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EARLY STRENGTH CONCRETE

THE USE OF
CALCIUM CHLORIDE IN CONCRETING

Explaining how to secure Accelerated Set • High Early Strength • Greater Strength at All Ages • Uniform and Dependable Curing • Cold Weather Protection • Increased Workability and Density

· CALCIUM CHLORIDE ASSOCIATION · DETROIT, MICHIGAN ·

INTRODUCTION

Calcium Chloride, used integrally in concrete mixes, accelerates the rate of hardening of portland cement concrete to such an extent that finishing may follow placing in one-third the usual time.

Higher early strength permits further construction to be placed or concrete opened for use in half the usual time. Days and weeks of waiting may be eliminated from construction schedules by the use of Calcium Chloride in concrete.

The urgent needs of the defense program have made it necessary to eliminate wasteful periods of waiting for concrete to gain adequate strengths. Thus Calcium Chloride has become one of the most important items on the list of materials and equipment needed to speed up urgent construction.

The more urgent the job, the more urgent is the need for Calcium Chloride. The more urgent the need for cold weather protection, the more does Calcium Chloride become a necessity. Its values should therefore be known to every architect, engineer, construction superintendent and official. It is the purpose of this booklet to explain the results secured by using Calcium Chloride in concrete and thus make possible more rapid and better regulated concreting schedules.

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THE USE OF CALCIUM CHLORIDE IN PORTLAND CEMENT CONCRETE

The addition of Calcium Chloride to Portland Cement Concrete produces definite measurable results which in no way change the normal chemical actions of cement except to complete them more rapidly.

Among these results are:

1. Acceleration of set—initial and final.
2. Increase of both early and final strengths.
3. Cold weather protection.
4. Uniform dependable curing.
5. Increased workability and density.

These advantageous results produce better quality concrete, in shorter time, at lower cost.

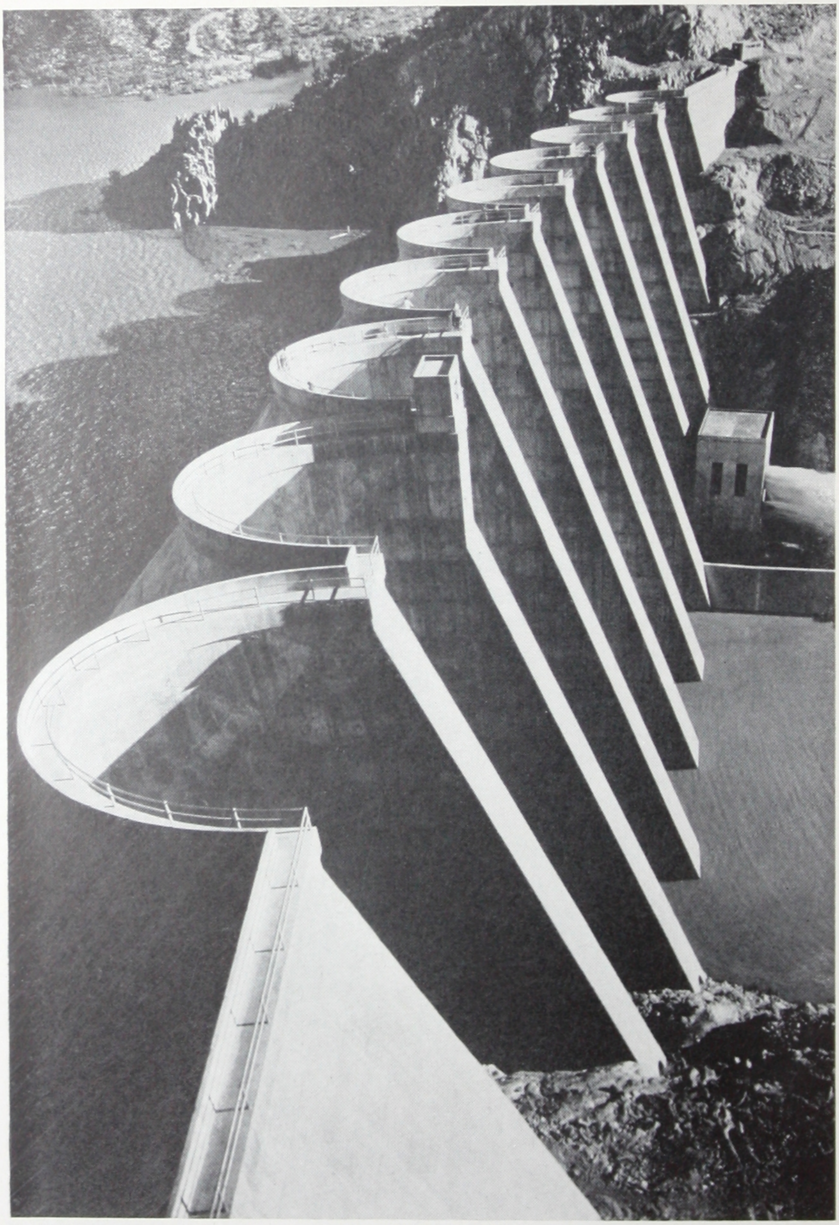
Tests made by the National Bureau of Standards and other recognized authorities both in laboratory and practical field tests show that Calcium Chloride

(a) Is effective with all types of Portland cements, standard, high early strength, white or colored.

(b) Is advantageous at all seasons of the year.

(c) Can be used in all types of concrete including structural, paving, mass, ready or transit mix and in concrete products.

Parkside Housing Project, Detroit, Mich.
Proper curing of structural concrete results in higher strength and longer life.



Among many major government projects in which hundreds of tons of calcium chloride have been used are the Grand Coulee and Bartlett Dams. Photos here taken at Bartlett Dam by the U. S. Bureau of Reclamation and reproduced through its courtesy.

DEFINITE MEASURABLE RESULTS FROM USE OF CALCIUM CHLORIDE

1. ACCELERATED SET FOR FINISHING

The use of Calcium Chloride provides higher early strengths in all concretes and the rate of hardening is accelerated at very early periods to produce sufficient stiffness for finishing in one-third the usual time. At normal temperature concrete is ready for finishing in one hour instead of the usual three hours. Thus finishing may follow placing more closely and enable finishers to leave the job by the time mixer crews are cleaned up and ready to leave. This saves much costly overtime and secures better finishing in daylight hours.

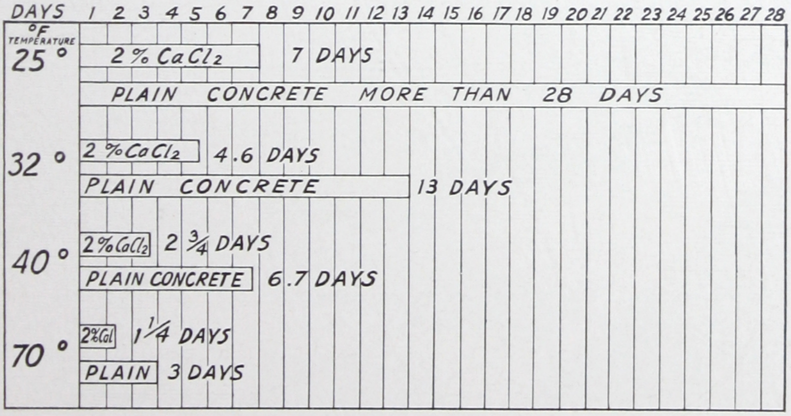
2. HIGH EARLY STRENGTH CONCRETE

Calcium Chloride cuts in half the time required for a given mix to acquire a definite strength, with all cements and at all temperatures from 20° to 90° F.

The National Bureau of Standards reports that . . . "all concretes containing Calcium Chloride had greater strength at all ages tested."

3. COLD WEATHER PROTECTION

In addition to the advantage of securing strength quickly so that cold weather protection is needed for a shorter period, Calcium Chloride is shown by recent tests to provide a definite measure of cold weather protection by the increased rapidity with which it causes a development of heat and by causing concrete, exposed continuously at temperatures as low as 25°, to acquire normal safe strengths which it does not acquire in a reasonable time without Calcium Chloride.



Days required for 1:2:4 concrete mix to attain 2000 p.s.i. with and without Calcium Chloride at various temperatures without cover or protection.

4. INCREASED WORKABILITY AND DENSITY

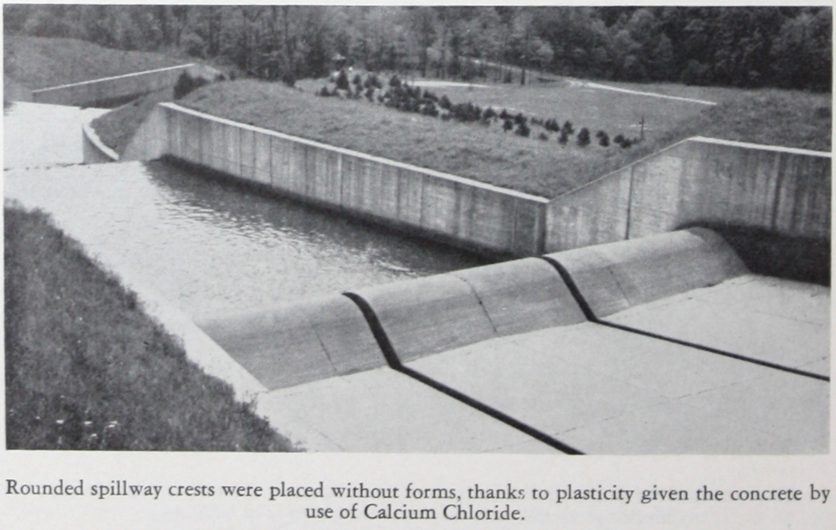
The use of Calcium Chloride increases the workability of concrete approximately 40% so that concrete with Calcium Chloride fills forms quicker and more completely and cuts down the labor necessary for pointing up and finishing. Being more plastic Calcium Chloride concrete flows faster in chutes, leaves the mixer cleaner and produces better and more homogenous surfaces.

5. (a) CALCIUM CHLORIDE SURFACE CURING

Calcium Chloride applied on the surface for curing, in accordance with the Standards of the American Society for Testing Materials, has long been recognized as a practical and efficient method of curing concrete. It is low in cost, provides a clean concrete surface at all times, involves no worries over prolonged inspection, and permits the use of the concrete surface at early ages—and still provides continued curing conditions to insure maximum ultimate strength.

5. (b) CALCIUM CHLORIDE INTEGRAL CURING

Calcium Chloride incorporated in the concrete mix, in accordance with the Standards of the American Society for Testing Materials—that is, either in the dry form placed in with the aggregates, or as a solution included with the mixing water—offers particular concreting advantages, principal of which is early strength concrete at all temperatures (equivalent early strengths developed in half the time required for plain concrete). Additional advantages include controlled volume changes, improved workability, and higher ultimate strength concrete.



Rounded spillway crests were placed without forms, thanks to plasticity given the concrete by use of Calcium Chloride.

VALUES OF ACCELERATED SET SECURED WITH CALCIUM CHLORIDE

Accelerated set secured by the use of Calcium Chloride in portland cement concrete provides these practical benefits.

1. Finishing may follow placing so closely that finishers may end their day's work by the time mixer crews have equipment cleaned up and ready to leave for the night. Finishing may thus normally be completed in daylight assuring better work and avoiding costly overtime.

2. Time of initial set for finishing may be cut to one-third the time or regulated in a practical way by variation of the amount of Calcium Chloride used so that scheduling of work of finishers can be controled instead of being left to chance.

3. Early final set permits covering of work in one-third the time required for plain concrete. This makes it possible to give concrete its protective covering before it can be seriously affected by loss of moisture* or lowering temperatures.

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*Public Roads Administration Report June, 1939.

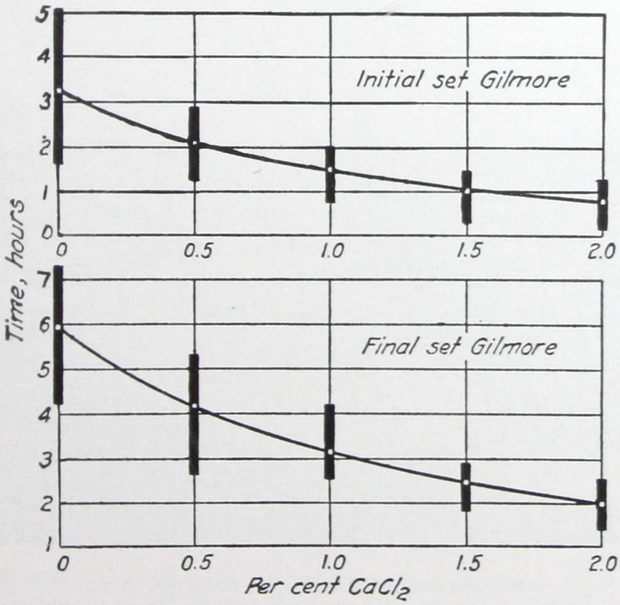


Figure 1.—Setting time of Eight Standard Portland Cements. (From National Bureau of Standards Reports.)

HIGH EARLY STRENGTH

Most important to architects and engineers in rating the value of higher early strength secured by using Calcium Chloride in concrete is definite proof that these benefits gained are permanent.

The National Bureau of Standards has made extensive tests as to the effects of Calcium Chloride in concrete and reports that "All concretes containing Calcium Chloride had greater strength at all ages tested." After years of tests by the California Department of Highways a report shows: "With 2% Calcium Chloride the average strength increased from 4030 at 28 days to 6045 p.s.i. at five years and 7700 *pounds per square inch at* 11 *years.*" (126% of the standard). (Nov., 1940, issue of the Journal of the American Concrete Institute.)

With definite assurance from many fact finding agencies that Calcium Chloride causes higher strength in concrete at all ages, the rate at which these strengths are secured is the governing factor in making use of its beneficial properties.

The main advantages gained by higher early strengths in concrete are:

Finishing may follow placing more closely, and time of set for finishing may be regulated by the amount of Calcium Chloride used.

Forms may be removed in less than half the time when Calcium Chloride is used in the concrete. Thus a smaller investment in forms and equipment will serve a larger project.

Williamsburg Housing Project, Brooklyn, N. Y.
Calcium Chloride was included in the specifications of the Housing Division of Federal Emergency Administration of Public Works for all concrete poured on this project at or below 50° F.

Adequate strength for placing additional concrete upon previous courses and safe strength for opening of pavements for use is also obtained in half the usual time by adding Calcium Chloride to the mix.

Just how much valuable time is saved by securing these strengths in less time than required for plain mixes is indicated by these facts.

At 25° Fahrenheit

Plain concrete developed only 510 lbs. p.s.i. in seven days. Concrete with 4% Calcium Chloride acquired 2000 p.s.i. in approximately the same time. Concrete containing Calcium Chloride thus attained a safe strength for removal of forms from unprotected concrete exposed to 25° temperature for the entire period. The fact that plain concrete did not acquire such safe strength in 28 days indicates more than a three week saving in time of waiting to proceed with further construction. While this in no way suggests Calcium Chloride is a substitute for normal protective measures, it does show that even in such extreme cases Calcium Chloride largely, if not completely, compensates for the slowing up in concrete at low temperatures and does supply definite protection at temperatures below freezing through its action in securing in one-third the normal time the final set which puts concrete beyond danger by freezing.

At 32° Fahrenheit

Exactly at the freezing point concrete mixes carrying a temperature of 70 when placed showed that after placing and maintaining at the freezing point the strengths were:

	1 Day	*7 Days*	*28 Days*
Plain concrete	100 lbs. p.s.i.	1530 lbs.	3150 lbs.
Concrete with 4% Calcium Chloride	790 lbs. p.s.i.	2890 lbs.	3730 lbs.

The one day strength of concrete with 4% Calcium Chloride approximated the five day strength of plain concrete. The seven day strength of concrete containing Calcium Chloride was 2890 lbs., far above safe opening strength and approximately the strength attained by plain concrete at 28 days, three weeks later.

These tests indicate that amounts of Calcium Chloride up to 4% are desirable in cold weather work although the quantity used for concrete at normal temperatures is 2%.

At 40° Fahrenheit

Concrete placed at 70°, subjected to 40° for 28 days.

	1 Day	*3 Days*	*28 Days*
Plain concrete	170 lbs. p.s.i.	700 lbs.	3780 lbs.
Concrete with 2% Calcium Chloride	950 lbs. p.s.i.	2130 lbs.	3980 lbs.

Three day concrete with Calcium Chloride approximated seven day strength of plain concrete. Thus with the use of 2% Calcium Chloride at these temperatures concrete would have been ready for use in three days against approximately a week needed by plain concrete.

This saving of time would have permitted re-use of the same forms during the period and would have permitted an additional concreting course to be placed and to be ready for use.

At 70° Fahrenheit

Plain concrete placed and maintained at 70° F. requires six days to acquire the standard 2500 lbs. compressive strength while concrete with 2% Calcium Chloride is ready for use in less than three days.

General Observations

The sound practice of requiring heating of water and aggregates, covering of concrete and maintenance of adequate surrounding temperature when concrete is placed at freezing temperatures would naturally have had the effect of increasing the strength of the concretes, which in these tests were subjected to temperatures as low as 20°—without heating or protection. But it is plain also that with such protection the use of Calcium Chloride in concrete will save more than half the time of waiting for concrete to attain useful working strength and will thus compensate for the reduction in strength of plain concrete placed at low temperatures.

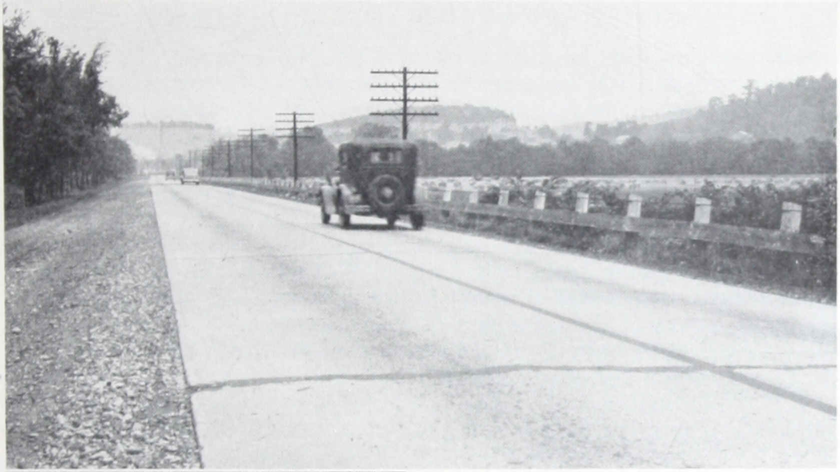
The use of additional standard cement will increase the early strength of concrete as well as the use of Calcium Chloride, but at many times the cost. Equivalent results may also be attained with high early strength cement but at a still greater cost so the simplest, most economical method is to add 2% of Calcium Chloride (2 lbs. per sack of cement).

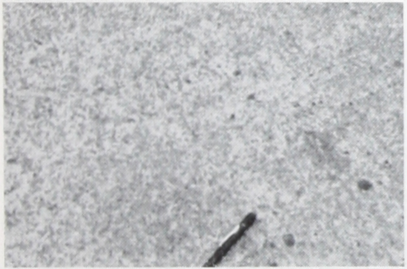
A rating of the comparative methods of securing high early strengths might be expressed thus:

To cut waiting time in half at any temperature use 2 lbs. of Calcium Chloride per sack of cement or for even greater strength at early stages add additional cement and Calcium Chloride or use high early strength cement and Calcium Chloride.

In military work where it becomes urgently necessary to build pill boxes or to mount heavy guns overnight, one day strengths adequate for the purpose can be secured by use of Calcium Chloride and a sufficient additional quantity of cement.

Whenever speed may be needed in concreting think first of Calcium Chloride. By use of Calcium Chloride finishing schedules may proceed without interruption.





16 YEARS OLD

The concrete pavement shown here, as it looked this summer, was surface cured with calcium chloride in 1924. Designated as Ohio Route No. 8 and U. S. Route No. 250, the section carries heavy traffic south from New Philadelphia, Ohio.

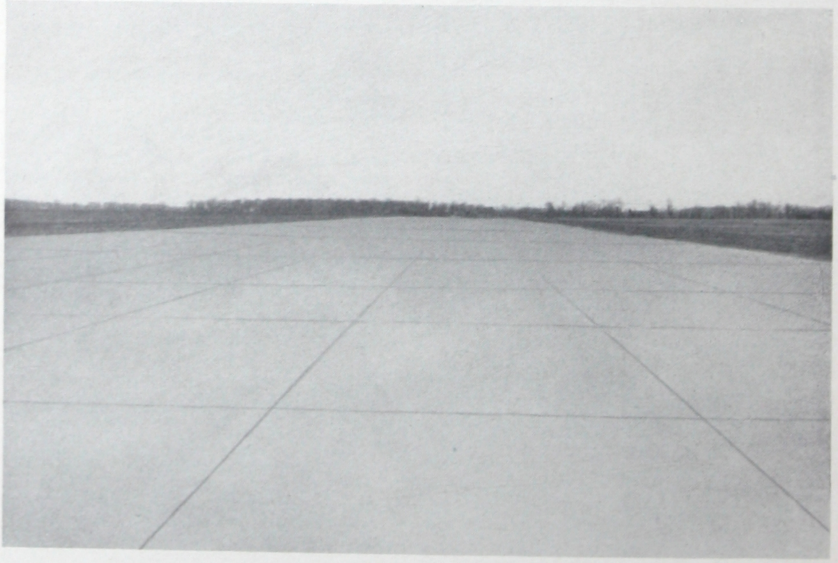
Calcium chloride was used in all concrete work—foundation, floors and sidewalls—at the Canton (Ohio) City Lines garage, constructed during late fall months.

COLD WEATHER PROTECTION

As the thermometer goes down concrete takes much longer to acquire safe working strengths. It is important to note how rapidly the rate of hardening is retarded by decreasing temperatures. A comparison of plain concretes with those containing Calcium Chloride at different temperatures emphasizes the increased gains from use of Calcium Chloride concrete at low temperatures.

*Time required for concrete to attain strength of 2000 lb.s p.s.i.
at temperatures given

	At	70° F.	40° F.	32° F.	25° F.
Plain Concrete	In	3 Days	6.7 Days	13 Days	6 Weeks
Concrete With Calcium Chloride	In	1¼ Days	3 Days	4½ Days	7 Days
Time Saved By Use of Calcium Chloride		1¾ Days	3.7 Days	8½ Days	5 Weeks



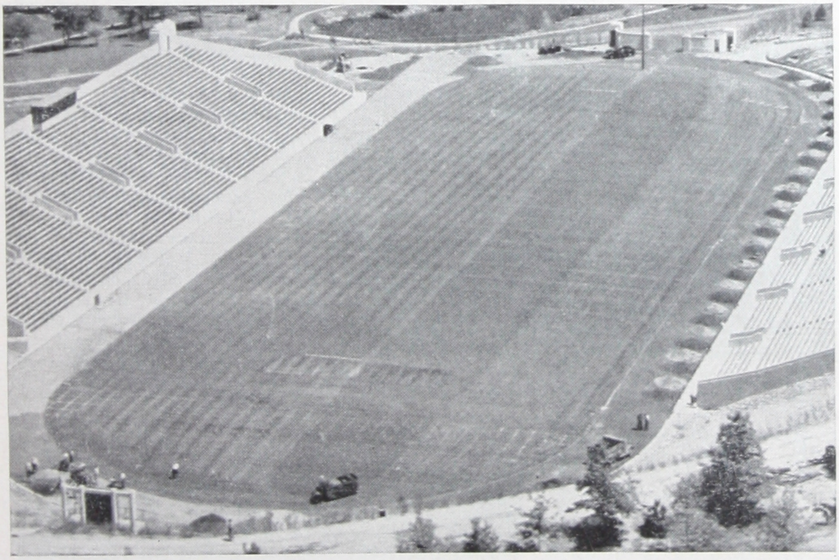
Bombers for Britain Ferry Station

One of the widened runways at Wayne County Airport, the "Bombers for Britain" ferry station. Photo taken during process of construction. This airport was brought up to the standards of the U. S. Army Air Corps as a "Bomber" ferry stop. Improvement started in the fall of 1940 and carried on through the winter. Calcium Chloride was used to secure early strength when concrete was placed in cold weather also for keeping excavated earth from freezing.

Calcium chloride in concrete completely compensates for lowering of temperatures from summer conditions (70° F.) to near freezing temperatures and does protect concrete against freezing temperatures to as low as 20° F. The heating of water and aggregates and the normal protection against low temperatures by covering, etc., will further help to reduce the time required to obtain adequate working strength in concrete.

These cold weather benefits secured with Calcium Chloride are due to both the high early strength secured and the earlier development of heat when Calcium Chloride is used. Thus without in any way obviating the desirability of protective measures Calcium Chloride does offer definite protection to concrete, when in case of adverse conditions the concrete may reach temperatures as low as 20° or lower and where adequate protective measures are difficult or impossible to provide. With normal winter protections and the use of Calcium Chloride concreting may proceed on normal schedules all year round, supplying both the adequate strength and the means of curing within the concrete itself.

*Note: One of the most important papers ever published covering research on cold weather concreting is a recent current report of the National Bureau of Standards presented in the 1941 Highway Research Board Proceedings.



Calcium chloride admixture in the concrete made possible year-round construction on this Canton (Ohio) stadium. Construction went forward almost irrespective of weather conditions and much of the concrete was placed in the fall and winter months. To accelerate the rate of hardening and improve the workability of the concrete, calcium chloride admixture was included in all concrete placed during cold weather. Engineers in charge found that the use of calcium chloride enabled concreting to progress rapidly and safely, with assurance of the highest quality of the finished product.

MORE WORKABLE CONCRETE

The values of quicker setting, higher early strength and automatic curing which are induced by use of calcium chloride have been the main reason for its ever widening use in the past 25 years. Contractors who have used it for these purposes have stated, however, that if it possessed none of these properties it would be worth its cost for the increased workability it provides. These statements from practical working contractors, verified by extensive field work are essentially as follows.

In projects where long chutes carry the mix into forms over a wide area, the increased workability induced by calcium chloride permits concrete to flow more rapidly in the chutes and requires less hand labor to keep concrete moving where it is impeded by blockades at turns or bends in the chutes. Such concrete also leaves the mixer cleaner with much less cleaning and pounding of mixer blades

Replacing a busy railway bridge without interruption of traffic is an engineering feat in which Calcium Chloride played an important part. Supporting piers 92 feet in height, constructed in winter, were cured and protected with Calcium Chloride in the mix. The contractor states that the concrete in which Calcium Chloride was used was denser, more homogenous and more plastic. It flowed into forms readily and produced a beautiful finish. With the high early strength secured by use of Calcium Chloride, piers were ready for steelwork on schedule.

The workability secured by Calcium Chloride in the mix made tamping of concrete unnecessary, avoided distortion of forms and therefore produced a circle for this turntable in which the actual deviation from a perfect radius was but $\frac{3}{16}$ inch (one-fourth of specification tolerance). Plasticity given the concrete by use of Calcium Chloride in the mix lets it flow into the forms easily, fills them completely, and makes close-limit work and better finish possible.

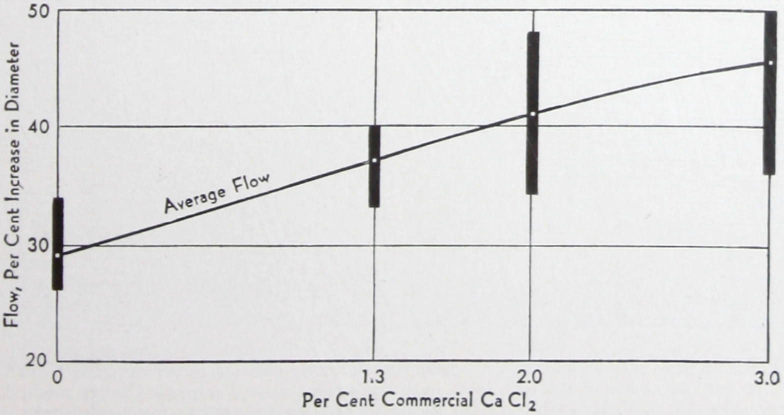
and drums. These benefits derived from an average increased flow of 41% when calcium chloride is added also cause the mix to flow into forms more readily and fill them completely. This eliminates the greater part of voids in corners and on surfaces where adhesion to forms causes pockets in ordinary mixes. Elimination of corner pocket and surface voids next to forms reduces pointing up to a minimum and leave a smoother, better appearing, more uniform surface. This more plastic quality produced by calcium chloride makes it particularly valuable for finer form work such as ornamental balustrades, pillars, etc., where smooth, attractive finish and close limits are required of the work.

The greater plasticity of the mix, induced by calcium chloride, makes it possible to reduce the amount of water which would otherwise be necessary to make concrete flow into forms. This reduction in gaging water reduces shrinkage and surface crazing and provides a denser and thus more waterproof concrete particularly desirable for foundation work.

Tests conducted at the National Bureau of Standards confirm the fact that the addition of calcium chloride substantially increases the flow of concrete. In the chart below reproduced from the Bureau's report, each point represents the mean of 72 determinations. Flowability was increased from 29 to 41 upon the addition of 2% of calcium chloride—representing an increase of 41%.

This increase in flow indicates increased workability. Thus by adding calcium chloride less water may be used and a flow equal to that of plain concrete may still be obtained. The reduction in water voids resulting from the use of less water in the mix produces denser concrete.

EFFECT OF CALCIUM CHLORIDE ADMIXTURE ON
WORKABILITY OF CONCRETE



(Chart from National Bureau of Standards report)

UNIFORM DEPENDABLE CURING

By good curing of either pavements, structures or concrete products is meant the establishment of favorable conditions for chemical action during the setting and early hardening period. It involves mainly the maintenance of sufficient moisture throughout the mass of the concrete. Given these conditions:

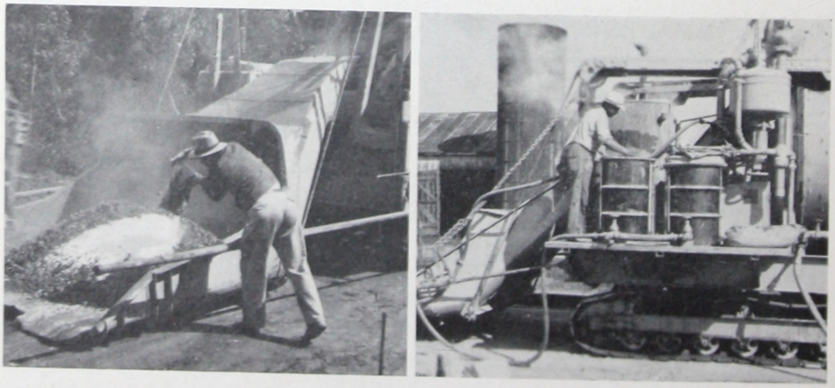
(1) A maximum quantity of cement will be hydrated (cured)

(2) The concrete will be subjected to a minimum volume change during the period of low strength.

The admixture of calcium chloride performs the function of moisture maintenance and temperature control and thereby effects curing in the simplest, most practical way.

The early strength developed as a result of the accelerating effect from the use of calcium chloride reduces the time necessary for protection with wetted burlap. Only 24 hours of wet covering is required when calcium chloride is used integrally as compared to at least three days for plain concrete.

The importance of curing structural concrete has become more apparent with the development of modern building practice. There is the same definite relationship between proper curing and ultimate strength of structural concrete that there is in paving concrete where careful control of curing has been practiced for many years. It is possible through the use of an admixture of calcium chloride to adequately and uniformly cure structural concrete including vertical units such as walls and columns and at the same time effect savings on the entire operation.



Calcium chloride may be added in dry flake form directly into the mixer's skip, as shown at left, or may be added in solution from tank equipment shown at right. Either method is approved in A. S. T. M. specifications. While these photos show concrete paving jobs, the same methods are used in concrete mixes on structural work.

SURFACE CURING OF PAVEMENTS, RUNWAYS, WALKS, AND OTHER FLAT SURFACES

Where the more rapid set and the higher early strength secured by integral use of calcium chloride is not desired the curing may be effected by surface application of calcium chloride according to A.S.T.M. Specifications C83-38 (see page 62). This method avoids necessity of hauling in and disposing of earth or straw or the maintenance of surface ponds. After the pavement is laid, it is kept covered for 12 to 24 hours with wet burlap, and then calcium chloride is spread at the rate of 1.5 pounds per square yard on the surface. A simple and inexpensive hand spreader may be used.

Making surface application of Calcium Chloride on concrete slab.

Application of Calcium Chloride, dissolving to form moisture holding film, for surface curing.

CALCIUM CHLORIDE IN MASS CONCRETE

The development of heat during the hydration of cement in mass concrete is a most significant problem in this type of construction, and recognition of its importance has resulted in the so-called "low-heat" cements being specified for general use in mass concrete. In connection with the use of such cements it is, however, of interest to note the comments offered by Mr. P. H. Bates of the National Bureau of Standards.*

"At this time there is a marked tendency to depart from the high-limed cements to the high-silica ones. These like the low-heat and sulphate-resisting types, unless very finely ground, are also slow-hardening. But if this characteristic could be overcome through the use of an admixture acting as an accelerator, we would have approached very closely the ideal all-purpose cement."

Calcium chloride has been used on a number of projects during low temperatures to offset the combined effects resulting from the use of these slower hardening cements and the strength retarding influence of low temperatures. In addition to its strength accelerating property, researches conducted by the National Bureau of Standards, as reported by Paul Rapp, Dec., 1934, concluded: "As the amount of calcium chloride is increased, the initial rate of evolution of heat is increased, but the total amount of heat developed at twenty-four hours does not differ by more than a few calories."

*15th Edgar Marburg Lecture, "Portland Cement," A. S. T. M. Vol. 40, Technical Paper, 1940.

VOLUME CHANGES

Volume changes are the cause of cracking in finished concrete, because the early stresses set up are in excess of the tensile strength of hardened concrete.

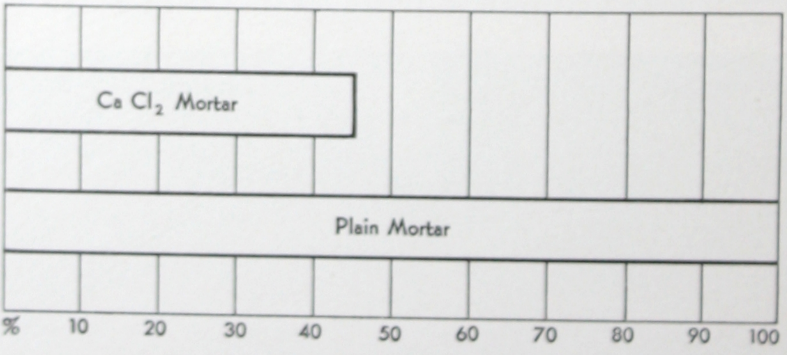


Figure 9—Relative Shrinkage of Cement Mortars.
(Data from Highway Research Board report by C. A. Hogentogler.)

Among the factors influencing volume change are: (1) variation in temperature conditions, and (2) variations in the moisture content of the concrete.

As indicated in Figure 9, the addition of calcium chloride will materially reduce shrinkage of cement mixtures. In this connection the following was reported before the Highway Research Board: "The reduction in shrinkage due to an admixture of calcium chloride is caused by a reduction in the rate of moisture loss, which, in turn, is due to the fact that crystallization (hardening) of the concrete has been accelerated."*

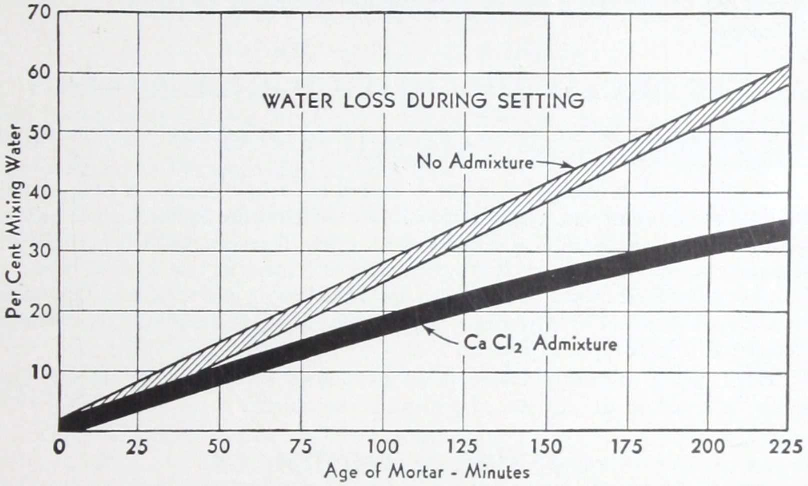


Figure 5—Effect of Calcium Chloride on Water Loss During Setting. (Chart from Highway Research Board report by C. A. Hogentogler of the Public Roads Administration.)

The data given below shows the extent to which calcium chloride, by lowering the vapor pressures of the moisture contained in the concrete, retards moisture loss through evaporation. Calcium chloride, in the concrete materially reduces the moisture loss to minimize shrinkage and to effect curing as well.

Table 1.—Percent of Original Mixing Water Retained in Concrete
(From research data reported by Ohio State University)

Age in Days	Plain Concrete	Concrete Integrally Cured with 2% $CaCl_2$
1	71%	83%
3	64%	76%
7	59%	71%
14	57%	58%
28	54%	64%

CALCIUM CHLORIDE IN TRANSIT-MIXED CONCRETE

For transit mixed concrete, varying procedures are used in introducing the calcium chloride. In cold weather, if the mixing is to start at once, the calcium chloride is added in flake form with the other ingredients at the batching plant.

When the mixing is to start enroute or on arrival at the job, the calcium chloride is not added till mixing starts and then may be fed in as dry flake. Or, if it has been put in the mixing water tank, it dissolves and is introduced with the mixing water. In warm weather work, the calcium chloride is not added until the mixer reaches the job, giving it one or two minutes of mixing before the concrete is discharged.

USE OF CALCIUM CHLORIDE IN MORTARS

In warm weather the use of calcium chloride in portland cement mortars provides quick setting and high early strength.

In cold weather calcium chloride is desirable for protection in both cement and lime mortars and their combinations. Calcium chloride makes cement mortars more plastic, workable and easier to spread, gives them quicker set, higher early strength and compensates for the slow action of cement at low temperatures. In lime mortars calcium chloride is used to prevent freezing although its action somewhat retards the set of lime mortar. Calcium chloride supplies definite cold weather protection in both types of mortar.

When using calcium chloride as an accelerator in mortar the amount used should be based on the amount of cement in the mortar.

CONCRETE PRODUCTS

Sales of concrete products (concrete pipe, blocks, burial vaults, posts, poles, piling, tile, etc.) to a large extent depend upon the manufacturing costs and the quality of the product. Manufacturing costs are influenced by the rate of production, losses through damage, and labor and equipment charges. The quality is influenced by strength developed, uniformity and water-proofness of the finished product. Since calcium chloride will favorably affect each of these factors, its use is now standard procedure by the majority of the country's best known manufacturers of these products.

Calcium chloride, by speeding up the set, permits the release of concrete products from the forms in at least one-half the time usually required. This reduction in time means that fewer forms are needed or that the output of the present forms can be doubled. The early strength developed by calcium chloride results in savings by reducing damage from breakage, chipping and cracking due to handling before the product attains its full strength.

CALCIUM CHLORIDE FOR PATCHING

Barricades, intended to protect the public from danger at pavement break-ups, are really one of the greatest hazards to the traveling public, particularly when left in place over night. The use of calcium chloride incorporated in the concrete mix for repairs of pavements will make it practical to eliminate such hazards except during the day. Concrete with calcium chloride will gain sufficient strength to support traffic so that the barricades can be removed before dark. Also concrete having calcium chloride in the mix will form better bond with the old concrete and will better insure the durability of the concrete repair.

EXPERIENCES BUILDING AND CURING CEMENT CONCRETE ROADS

By HARRY TUTHILL
Superintendent of Highways, Suffolk County, New York.

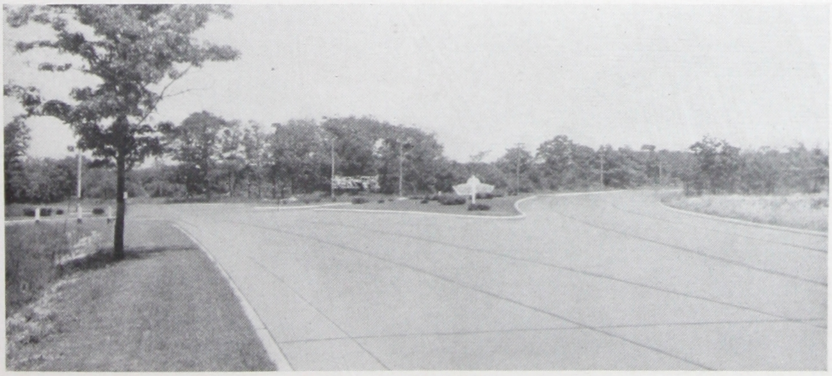
(Reprinted from *Public Works* Magazine)

We do not believe it is in order for us to say that we in Suffolk County have found a universal cure for the unsatisfactory results that sometimes take place in constructing concrete pavements. In the words of the Greek philosopher, Syrus, "You cannot put the same shoe on every foot."

There are so many operations in the construction of a concrete pavement that are either not appreciated or cannot be accurately controlled—plus differences in topography, atmospheric conditions, temperature ranges, subgrade soils and materials—that an ideal concreting formula for one highway department may meet with only mediocre success under the different conditions experienced by some other department. Certain aids to better concreting are fundamental, however, and it is with this in mind that we report on the results we have obtained in Suffolk County.

Suffolk County's concrete paving program may be said to have started in 1930, at which time the county highway department was established. Today, we have 127 miles of concrete pavement, comprising nearly 90 percent of the total county road mileage. The paving has been uniformly successful and we have had no failures, scaling or checking in any pavement to date.

Naturally, we believe that our specifications are right and that our system of control is efficient, but we must also give credit to the curing method we have employed in every mile of pavement constructed—the integral use of a 2 per cent solution of calcium chloride.

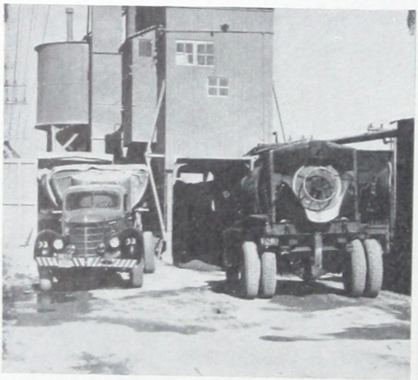


An example of Suffolk County concrete paving: intersection of Sebonac and Sandy Hollow Roads, Route 39.

SPEED WINTER CONSTRUCTION WITH CALCIUM CHLORIDE

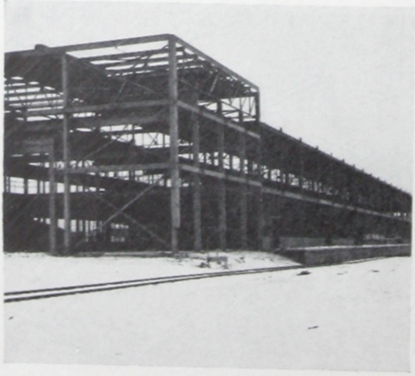
The Briggs Manufacturing Company of Detroit found that it needed a new, large plant for the manufacture of automobile mouldings. It needed this new plant not a year hence, but just as soon as it could possibly be erected. This meant cold weather construction.

In the maxim, "It can be done!", lies the success story of the automotive industry. Plus the fact that the industry has always taken advantage of every worth-while and practical means to an end. So it was only typical that the Briggs Manufacturing Co. acted fast, let the contract for its new building promptly to the W. E. Wood Co. of Detroit, and saw excavation started about October 1st.

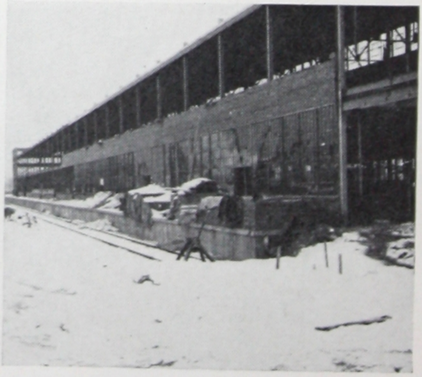


1. Loading transit-mix trucks at plant of Cooper Supply Co.

2. Delivery and pouring of concrete on November 4.



Viewing same section of the Briggs Plant, December 1.



Exterior practically completed, December 27.

Cold weather had just arrived when it came time for constructing the concrete foundation, but the Cooper Supply Co., also of Detroit, knew the formula for cold weather concreting. As suppliers of transit-mixed concrete for many another job, when temperatures were freezing and below, they had found the answer in the integral admixture of calcium chloride with the concrete.

6,000 cubic yards of concrete were mixed in transit and delivered by the Cooper Supply Co. for the foundation and floor of the Briggs plant. Most of it was poured during cold weather, so most of it contained the vital calcium chloride admixture.

Combined with other modern aids to construction, the use of calcium chloride permitted the work to go ahead rapidly. Steel was erected without delay, walls and windows went in, and the present rate of progress will see the structure fully completed early in February—four months from the time the earth was first broken in excavation.

COLD WEATHER DIDN'T STOP THIS JOB

Charles E. Firestone and L. W. Kilgore, architect and contractor respectively, of Canton, Ohio, knew what to do last fall to hurry cold weather construction of the new $125,000 garage of the Canton City Lines, Inc.

Mr. Firestone specified and Mr. Kilgore used calcium chloride in all of the concrete work—foundation, floors and sidewalls—that went into the building of this streamlined home for Canton's buses. Combining the use of calcium chloride in concrete with other modern construction methods, the structure took shape rapidly and the bus company found its new quarters ready for occupancy the week before Christmas—just a little over three months from the time ground was broken.

The new building, 190 x 180 ft. in size, accommodates 167 buses, and also houses the offices of the company. To complete the modernization, a calcium chloride stabilized parking area has been provided at the rear of the building.

Calcium Chloride was incorporated in all concrete placed in winter construction of this Canton, Ohio, Bus Terminal.

MOHAWK TRAIL REBUILT THROUGH ZERO WEATHER CONCRETING

CALCIUM CHLORIDE IN MIX AIDS PROTECTION

Among the many New England highways which suffered severe damage during the devastating floods and hurricane of 1938, a 4-mile section of the famous Mohawk Trail west of Charlemont, Mass., probably came closest to being removed from existence.

Describing the restoration of this flood-wrecked road in the December, 1939 issue of *The Excavating Engineer,* Spencer Jones reports, "No one could possibly realize the hardships encountered by men and machines in rebuilding the Mohawk Trail and rechanneling the river unless they had actually seen the ruins of this road through Cold River valley. . . . In brief, the job consisted of the clearing, deepening, and in some places the widening of the river channel; the building of more than 5,000 feet of heavy and high concrete retaining walls to protect the roadbed from possible future floods; the replacement of all washed out highway fill and the raising and widening of the roadbed in several spots; the laying of reinforced concrete, cast iron and perforated bituminous coated corrugated metal drainage pipe; the placing and cementing of large quantities of rip-rap above the concrete retaining walls in many locations, and the construction of rock embankment where no retaining wall was built; and finally, the surfacing of the road, the fine grading, the fence work and other miscellaneous items."

Calcium chloride was "in the mix" for these concrete retaining walls.

Rehabilitation operations were started in October, 1938 by C. J. Maney Co., contractors, and continued, reports the author, "throughout a stormy and cold New England winter. In fact, there was hardly a thaw all winter long, and the ground froze to a depth of four and five feet.

". . . Ice was continually forming in the footing trenches and on the concrete formwork, as well as accompanying heavy snow on the hauling road and in the riverbed. The difficulty of continuing the operations at persistently sub-zero temperatures can hardly be described adequately. Under such conditions as these, practically all the concrete on the job, totalling more than 25,000 cubic yards, was poured.

"Heating of the materials, and cold weather protection in all its phases, was, of course, another major problem in handling the concrete work. At the batching plant a large upright steam boiler was set up and steam lines were run from it through the materials. Tarpaulins were used as coverings to retain heat. As might be expected in sub-zero weather, it was necessary to keep the concrete materials heated continually—a 24-hour-a-day proposition.

"Calcium chloride was added to the mix, and the water which was supplied to the mixers from the river by 2½-inch force pumps, was run through preheating coils. In addition to these precautions, it was still necessary to keep the drums of the mixers heated by Hauck gasoline heaters. The poured concrete was kept covered in the usual manner with tarpaulins, and salamanders were kept going 24 hours a day.

"The quality of the concrete, so thoroughly protected from the cold at every stage, turned out to be superior, and well worth the trouble taken to guard it."

CANADIAN CITY SPEEDS PAVING

In The Canadian Engineer, L. McL. Hunter, Roadway Engineer of Ottawa, Ontario, relates some interesting experiences with the use of calcium chloride in concrete paving. The greater part of Mr. Hunter's article is reprinted here:

"Three years ago the city of Ottawa, Ont., started a program of reconstruction of pavements where street cars operate. These streets were situated mostly in the central or shopping district.

"The first street started was Bank Street, between Sparks and Gladstone Avenue. This was about 1¼ miles in length. Work had progressed for only one week when the shopkeepers held a meeting to try and have the work 'hurried.' It was the delay in the setting of the concrete that seemed to worry them. Twelve to fourteen days were to be allowed for this before the asphalt would be placed. It was decided to hasten the 'set' of the concrete by using calcium chloride. Two and a half pounds were used to the bag of cement. Forty-eight hours after the concrete was laid with the calcium chloride in it, it was found sufficiently strong to allow the asphalt to be placed and this contract was completed in less than half the time it was expected to take.

"Since then, the use of calcium chloride has been ordered, and is included in all paving contracts which the city has carried out.

"In the reconstruction of the pavement on Sparks Street from Elgin to Bank, and which is Ottawa's main business thoroughfare, calcium chloride was added dry to the mix at the rate of 2½ lbs. to the bag of cement. The time taken for this job was twenty-one working days. Ordinarily, this work would have taken six weeks.

"In the concreting of service pay cuts throughout the city, amounting to from ten to twelve thousand square yards per year, we have used calcium chloride with the result that we can top these usually the day after concreting. The benefit of this is obvious, the asphalt pavements are always in first class condition.

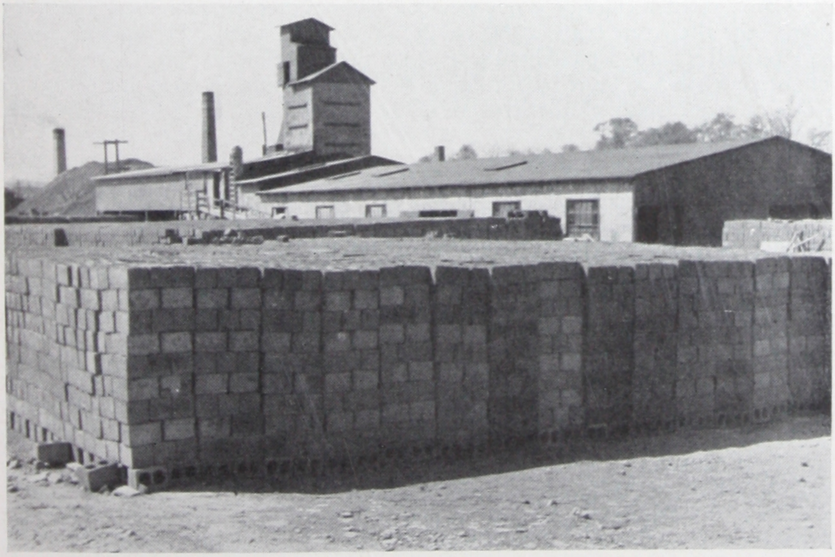
". . . . The use of calcium chloride was introduced into concrete sidewalk work this year during freezing weather. Temperature varied from zero to 20 deg. above. These walks were protected only with tarpaulins; no freezing of the concrete occurred."

CINDER BLOCKS BY THE MILLION TO MEET WASHINGTON'S DEMAND

One of the largest concrete products manufacturers serving the nation's capitol and surrounding area is the Washington Concrete Products Corporation, located at South Washington, Virginia. Now producing and selling well over 3,000,000 cinder blocks a year, the business of the Washington Concrete Products Corporation has grown by leaps and bounds since its first block was made in 1924. In those days, according to H. A. Davis, an official of the company, the public would say, "How in —— can you build a house out of ashes?" Today, it has become a problem to meet the demand.

For the past several years, every block that has left this plant has contained an admixture of calcium chloride. With 2 lbs. of calcium chloride added to every sack of cement used in winter, and 1 lb. to every sack in summer, pallets can be stripped off in 24 to 48 hours and blocks placed in yard storage. Instead of the usual 28 days required for curing, the blocks attain sufficient strength for shipment, if necessary, at 6 or 7 days. Exhaustive laboratory tests, performed for the Washington Concrete Products Corporation, have shown that calcium chloride admixture enables their blocks to reach 56% of 28-day strength in 2 days, and 80% at 7 days.

Mr. Davis reports that year-round use of calcium chloride admixture adds only about ¼c to the cost of each block—a slight consideration indeed for the money-making advantages gained.



Blocks are safely placed in yard storage at 24 to 48 hours.

BLOCK MANUFACTURER SPEEDS CURING

(Reprinted from February, 1940 issue of *Concrete* Magazine)

The concrete products business of Robert Dempsey at Hudson Falls, New York, has prospered considerably since the day he established his plant as the pioneer concrete block manufacturer north of Albany. Last year Mr. Dempsey's plant turned out more than 500,000 concrete blocks plus a sizeable number of pre-cast curbing units.

Sales efforts of the Dempsey organization are extended over a hundred-mile radius of the plant, so deliveries are not infrequent to parts of Vermont and western Massachusetts as well as throughout northern New York. Commercial and other public buildings such as hospitals, schools and theatres consume a good part of the Dempsey production, although the demand for use in private home construction has greately increased during recent years.

To expedite production and increase strength, Mr. Dempsey has used calcium chloride in his concrete products for eleven years. In his own words, he "couldn't get along without it." Among the advantages, he claims, are higher strength, no efflorescence, and the fact that blocks can be placed in the yard at the end of the first day, and delivered at the age of two weeks, instead of the 28-day age normally required.

Use of calcium chloride is not merely a cold-weather measure at the Dempsey plant. The admixture is a valuable aid in summer, too, when it becomes necessary to replenish rapidly depleted products stock piles. Ordinarily, Mr. Dempsey recommends a solution made by dissolving 28 lbs. of calcium chloride in a 60-gallon drum of water, although the strength of the solution may be reduced somewhat during warm weather.

A section of the Dempsey storage yard.

CONCRETE PRODUCTS MADE FASTER, STRONGER, BY EASY CURING METHOD

In a paper on "The Practical Application of the Use of Calcium Chloride in the Manufacture of Concrete Masonry Units," H. F. Clemmer, Engineer of Materials, District of Columbia, presents some facts of great importance to concrete and cinder products makers. Mr. Clemmer's paper, which was delivered at the recent convention of the National Concrete Masonry Association, is reviewed by *Pit and Quarry* magazine as follows:

"By assuring positive and uniform conditions throughout the mixture, the use of calcium chloride will result in a uniformly higher quality product. Strengths usually attained at the end of three days are obtained at the end of a 24-hr. period, ultimate strength is increased, and the lack of uniformity due to alternate wetting and drying is eliminated when calcium chloride is used, Mr. Clemmer stated. He is also of the opinion that the admixture tends to densify the product and lower absorption.

"Calcium chloride by increasing workability allows the use of the minimum amount of water, the resulting decrease in the water-cement ratio producing higher strengths and an accompanying increase in density, hardness and the ability to resist shrinking. The use of calcium chloride with high-early-strength cements is particularly valuable, according to the speaker.

"Since the rate of set and the development of early strength of Portland cement becomes progressively slower as the temperature falls, the value of calcium chloride in concrete products is materially increased in cold weather. Mr. Clemmer pointed out that units cured at a temperature of 90 degrees have 10 percent more strength than those cured at 70 degrees. The period of protection or inside storage can be reduced one-half or more and the danger of frost damage correspondingly decreased when calcium chloride is an integral part of the mix.

"Contrary to the belief of some producers, calcium chloride is never responsible for efflorescence. This condition is due to soluble salts in the cement or aggregates used and the presence of moisture in the wall plus the existence of capillary channels through which the moisture-carrying dissolved salts can find their way to the surface. Calcium chloride, due to its ability to take up moisture from the air and to dissolve in that moisture, can not be recrystalized and deposited."

Substantiation of Mr. Clemmer's remarks is found in the experience of J. A. Whitman & Son, of Midland, Mich., makers of concrete blocks, as related a short time ago in *Rock Products* magazine. This company reports that:

"Curing under cover is effected in from 16 to 24 hrs., depending upon atmospheric conditions, by the use of calcium chloride added to the dry aggregates and cement at the mixer. From 1 to 1½ lbs. of calcium chloride is used to a sack of cement. This admixture, it is claimed, reduces moisture loss in the completed block and not only increases the compressive strength at 24 hrs. but adds materially to the ultimate strength of the unit after it has been laid in the wall. A part of this strength increase is an indirect result, because the admixture is said to improve the workability of the concrete, an important feature when the tamping action is taken into consideration."

CALCIUM CHLORIDE USED EXTENSIVELY IN NATIONAL DEFENSE PROJECTS

Recent trade journal articles indicate that calcium chloride is being used quite extensively in concrete on many national defense projects. In describing activities among a number of ready-mixed concrete plants holding Army and Navy contracts, *Rock Products* magazine reports:

"Most of the ready-mixed concrete plants visited were seen in the early winter months when temperatures fluctuated from 50 deg. F. to well below freezing. One plant had delivered concrete at 12 deg. F., but extra precautions and protection were taken by the contractor on the job. In other cases, no concrete was delivered unless temperatures were as high as 25 deg. F. with a rising curve. Lower temperatures were allowed according to protection available for the fresh concrete and for inside pours.

"All the plants, including those temporarily located, were equipped for heating mixing water and some were installing steam equipment for heating aggregates. Engineers are preferring a concrete temperature of 70 deg. F. when placed in the forms.

Line-up of trucks at Kingston Trap Rock Co. batching plant at Fort Dix, N. J., illustrating severe winter conditions. See description, page 21.

"One plant was using high early strength Portland cement and many were adding calcium chloride to the mix. Calcium chloride is required on some contracts when the temperature drops to 40 deg. F. in proportions of about 2 lbs. to each sack of cement, applied in the mixers in a saturated solution."

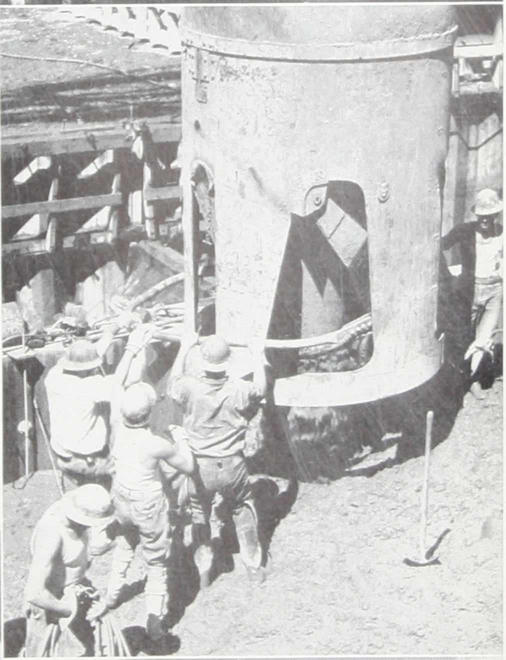
Citing specific locations where projects are underway, another *Rock Products* article describes the operations of the Kingston Trap Rock Co., engaged in filling an order for 65,000 cu. yds. of ready-mixed concrete for piers, foundations and floors for barracks, and other buildings at Fort Dix, New Jersey. On this job, the article relates, "No high early strength Portland cement is used but calcium chloride is required at temperatures below 40 deg. F." The same producer holds the concrete contract for storage warehouses at the Raritan Arsenal and, here again, *Rock Products* explains, "Calcium chloride is also used in this plant at pouring temperatures below 40 deg. F."

Michigan Roads and Construction reports that, "Using modern winter construction methods, the Thomas E. Currie Co. of Detroit completed paving aprons and runways 36 days ahead of schedule (Ed: At the Army's Selfridge Field near Mt. Clemens, Mich.) . . . More than 28,000 square yards of concrete pavement was involved. The contract called for completion in 90 days . . ." The magazine quotes Leet M. Denton of the Currie Company in a brief description of construction methods as follows:

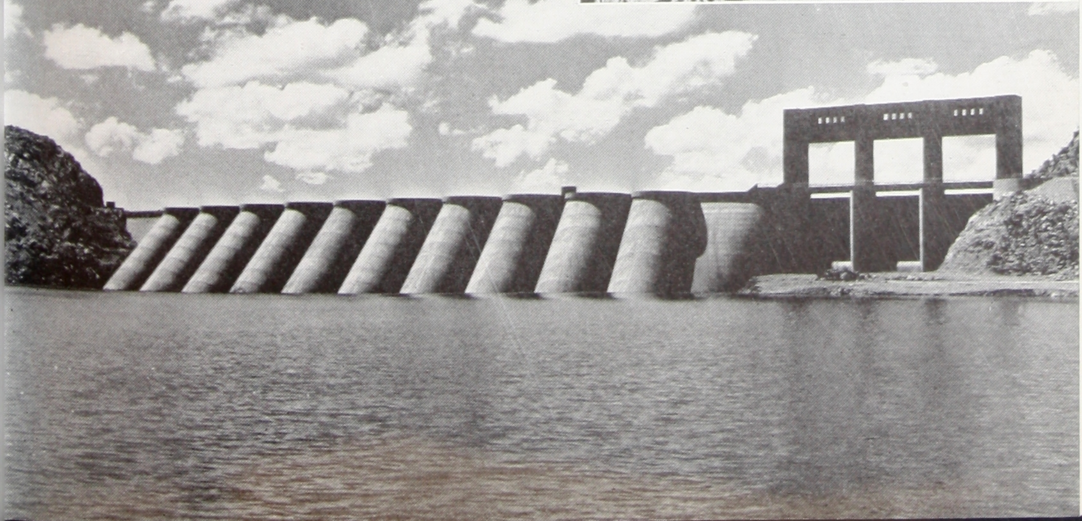
"The entire area was covered with a heavy layer of straw and hay to protect against frost action. This cover was removed in front of grading operations and then replaced until paving began.

"Concrete aggregates were heated. An admixture of calcium chloride was used, however, in special situations. 'High Early' cement was substituted for the regular Portland cement. Mixing water was heated by a portable hot water heater . . . The new paving was covered with a 2-foot mat of straw which was left on for 21 days."

> ". . . SOME CONTRACTORS find it profitable to use both extra cement and calcium chloride as a means of cutting down the length of the heating period, and thereby reducing the cost involved in keeping the inclosure warm."



Calcium Chloride was used in concrete on Bartlett and Grand Coulee Dams. Photos by courtesy of the U. S. Bureau of Reclamation.



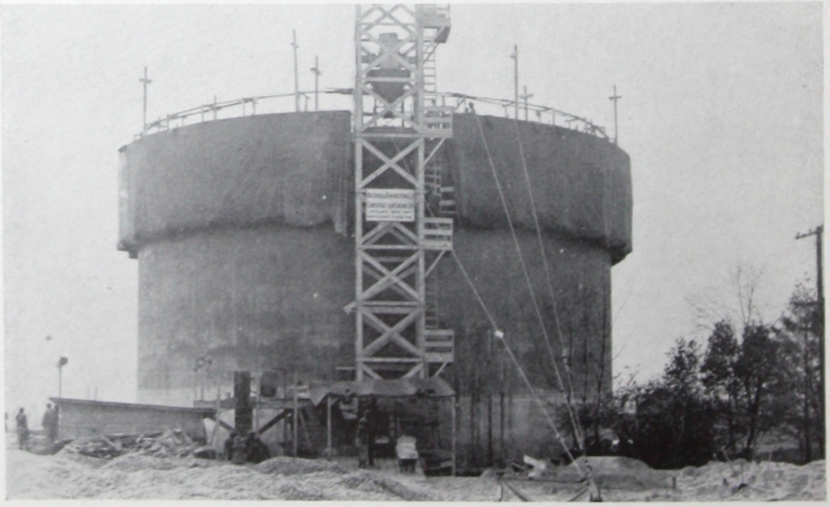
CALCIUM CHLORIDE SPEEDS CONSTRUCTION OF WATER TOWER AT FORT BRAGG

(Reprinted from *The Constructor*)

Almost over night 60,000 men are moved into a town of 6,000 inhabitants. This is what happened when our national defense program started pouring army officers and trainees into Fort Bragg, North Carolina. The land owned and leased by the United States is some 125,000 acres, making it the largest cantonment in the United States.

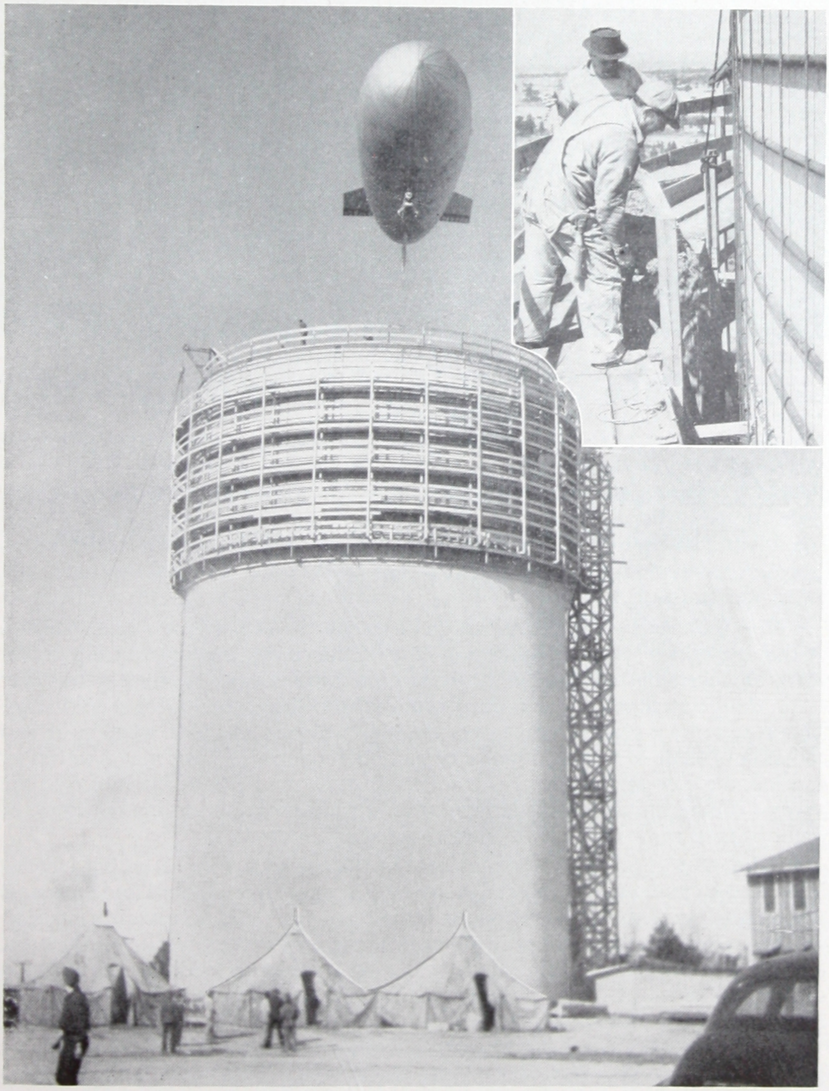
Living facilities for the men had to be provided in the shortest possible time. We all know that the water supply is a major item, and naturally the original water facilities were entirely inadequate. To provide a supply with ample storage meant the construction of a 1,000,000 gallon elevated Hewett System reinforced concrete water tank pictured here. This is in addition to three tanks aggregating 1,100,000 gallons capacity already located at the Fort. The introduction of calcium chloride into the concrete mix facilitated the early completion of the tower.

Calcium Chloride was introduced into the concrete mixture in solution form. The use of calcium chloride was very important because speed and high early strength were necessary factors. Of the 2,300 cubic yards of concrete in the structure, all of which was poured with a maximum of six bags of cement per cubic yard, none tested less than 3,500 pounds compressive strength in 28 days, most of it far exceeding this test.



Temperature ranged between 12 and 30 degrees during construction. Photo shows tank three days after start of concreting.

The prevailing temperature during construction was between 12° and 30°. Thus, one of the heretofore objections to placing concrete during cold weather was entirely eliminated, and the two outstanding required qualities, speed, and high early strength, resulted from the use of calcium chloride.



Concrete tested over 3500 lbs. compressive strength in 28 days, with calcium chloride in the mix. Inset photo shows pouring of concrete shell on outside tank walls.

This busy warehousing district on 12th St. S.W. in Washington, D. C., was provided with a new street surface in less than 24 hours, due to the rapid hardening of concrete containing calcium chloride.

CONCRETE PAVEMENTS OPENED TO TRAFFIC IN 24 HOURS

EXPERIENCE OF THE DISTRICT OF COLUMBIA'S ENGINEER DEPARTMENT

With the continued improvement in the properties of portland cement, control of the aggregates and the application of efficient curing methods during recent years, engineers have been able to produce portland cement concrete which will attain design strength under normal conditions within a period of 3 to 7 days. This represents a great advance over the old-fashioned methods whereby it was common practice to wait two weeks or more before opening pavements to traffic; and too, the economic value of this saving in time is of great importance to the affected communities—particularly business organizations and in the reduction of traffic hazards made necessary by the extended use of detours.

Although recognizing the significance of this advance, it is becoming increasingly evident in densely populated areas—and at street intersections and entrances to business establishments and public buildings—that it is necessary to develop still greater early strength in portland cement concrete if the time for costly street closings is to be reduced to a minimum. Also in concrete building construction the early removal of forms and continuance of adjacent pours are of great economic importance for similar reasons.

In view of these facts, considerable investigative work has been carried on in the past few years as to the practicability of producing design strength in concrete within twenty-four hours. Several methods of producing early strength were developed and proven practicable, and it was with a full realization of the importance of producing early strength that the Engineer Department of the District of Columbia included the following in the Standard Highway Specifications as early as 1933:

"Early strength concrete may be attained by one of the following methods, or a combination thereof:

(a) By the use of high early strength portland cement in lieu of the standard portland cement specified in the same amount.

(b) By the use of additicnal standard portland cement (the total amount shall not exceed seven and one-half (7½) bags of cement per cubic yard of concrete). The use of additional standard portland cement will be paid for at the price bid for this item.

(c) By the use of an accelerator incorporated in the concrete mix. The use of such an eccelerator will be paid for at the price bid for this item."

In applying these provisions, the general practice of this department is to use first the accelerator, calcium chloride, and if sufficient early strength is not obtained with the mix under consideration by the use of calcium chloride only, additional standard portland cement (of the same brand as is being used on the project) is added to the concrete mix. The satisfactory results which may be obtained by using high early strength cement and an accelerator are fully appreciated but, due to the convenience of having the standard portland cement readily available and the fact that the color of the concrete will not be changed, the practice of increasing the unit amout of cement has proven more practical, especially when it might be important to use early strength concrete for only a portion of the project; and too, the increase in the unit cement content will represent a permanent improvement in the quality of concrete. From a number of years of practical experience it has been established that this procedure, involving the use of an accelerator and additional standard portland cement may be depended upon to produce the required results in actual construction with no particular provision or change in construction practices and curing methods.

A practical application of this method of obtaining high early strength concrete is illustrated in the recent construction of a project on 12th St. S. W. in Washington, D. C. This street passes through a heavily trafficked warehousing district, where the closing of the street for the usual length of time (3 days) necessary to obtain sufficient strength of concrete, to safely carry the heavy loads of commercial traffic, would have incurred serious inconvenience to the business establishments abutting the pavement. However, it was actually possible to open this particular street to the heavy traffic in less than 24 hours (in many cases the concrete poured in the afternoon was open to traffic the next morning) and it is especially worthy of note that these results were obtained without any particular increase in cost or undue preparation or inconvenience.

Within the area of the warehousing district along this project 25 sets of concrete field tests specimens in the form of beams were made and broken in flexure by a portable apparatus used in control of all highway work. The recorded results represent the average of at least two breaks on each beam. The strength of the standard proportioned concrete (1.60 bbls. cement per cu. yd.) using 2 per cent calcium chloride,* by weight of cement, as accelerator in the mix were as follows:

TABLE I

1.6 barrels of cement per cu. yd.

Specimen Age (hours)	Flexure Strength p.s.i.
24	232
21	375
17	518
21	375
23	490
20	299
17	442
24	426
18	410
—	——
Avg. Age 20	Avg. Strength 396

TABLE II

1.85 barrels of cement per cu. yd.

Specimen Age (hours)	Flexure Strength p.s.i.
23	482
16	426
19	474
19	514
16	314
15	402
22	506
18	506
22	601
22	458
Avg. Age 19	Avg. Flexural Str. 470

By using a conversion factor between flexural and compressive strength of pavement concrete of 5.5 which has been determined from extensive comparative field tests to be approximately correct for the age and range of strength encountered, it is possible to evaluate the strength of this concrete in terms more familiar to the construction engineer. The average of the above tests in compressive strength would therefore be 2180 p.s.i. at an average age of 20 hours.

The strength of the concrete in which an extra bag of standard portland cement was added to each cubic yard of concrete plus 2 per cent of calcium chloride by weight of cement, may be noted from Table II.

Again using a conversion factor of 5.5 we find that this average of 470 p.s.i. in flexural strength is approximately equal to 2580 p.s.i. in compression. It may be noted that the increase in cement (approximately 15%) increased the early strength 20%. As stated this increased cement content also means a greater durability as well as greater maximum strength.

The above results were obtained by the Division of Materials from the test beams made and broken on the job of concrete of similar qualities as that used in the concrete slabs themselves. It is important to note that the satisfactory results obtained are due in some measure to the thoroughly wetted burlap curing methods employed. This has been demonstrated from numerous laboratory tests to be of particular importance at the earlier ages after placing the concrete.

The increase in cement content and greater strength is accompanied by better workability, greater density and therefore increased durability. It also has been demonstrated by this Department that the increase in the unit cement content is an important factor in overcoming the effect of lowering temperatures, particularly at early ages. It follows that the benefits noted above by using calcium chloride and an extra bag of cement per cubic yard in our highway work are equally advantageous in structural concreting. As an example the early removal of forms results in an economic saving that more than justifies the relatively small increase in cost of the concrete.

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*Calcium chloride is added in the dry form in with the materials in the skip. Due to its uniform gradation it may be measured by volume as satisfactorily as by weight.

CONCLUSIONS

The test results definitely indicate the effectiveness of calcium chloride and added portland cement in producing design strength of concrete in twenty-four hours under field conditions. The cost of calcium chloride as an accelerator is a negligible factor and its application is simple and convenient. It has been demonstrated that for average conditions where increased early strength is desirable, the incorporation of calcium chloride plus extra standard portland cement is a most practical method. This Department has used the method for many years and found it to be most convenient and practical where time saving is required in concrete construction and has especially noted the satisfactory results under a variety of conditions. The fact that only standard methods of placement and care in the curing of concrete are required lends itself particularly to normal contract work. It is believed that under general conditions the addition of calcium chloride only, as illustrated above, may be expected to produce sufficient acceleration of strength development, but in those cases where greater early strength may be required, the addition of an extra bag of standard portland cement per cubic yard may be depended upon to produce the necessary results.

Calcium Chloride was included in the concrete used in winter construction of this Grand Rapids, Michigan reservoir.

TECHNICAL ABSTRACTS AND REFERENCES

During more than 25 years in which calcium chloride has been used as an admixture for portland cement concrete and mortar, many extensive and carefully controlled tests have been conducted both in the field and in the laboratory by unbiased authorities. In a booklet of this size it is impossible to include the results of all of the work that has been done in this field. The references used, unless otherwise indicated, are taken from Vol. 14 of the Journal of Research of the National Bureau of Standards, since this represents the most recent complete investigation.

EARLY AND ULTIMATE STRENGTH

1:3 STANDARD SAND MORTARS

"Strengths: A summary of the 1:3 standard sand mortar strengths is given in Figure 10. This graph shows the strengths of the 8 standard portland cements with the addition of various percentages of calcium chloride. Not only were the early strengths of portland cement mortar greatly increased by calcium chloride. but the 1-year strengths were also increased. The results of the tests show that the mortar containing 2 percent of commercial calcium chloride has a strength approximately 15 percent greater than the plain mortar at 1 year; the strength

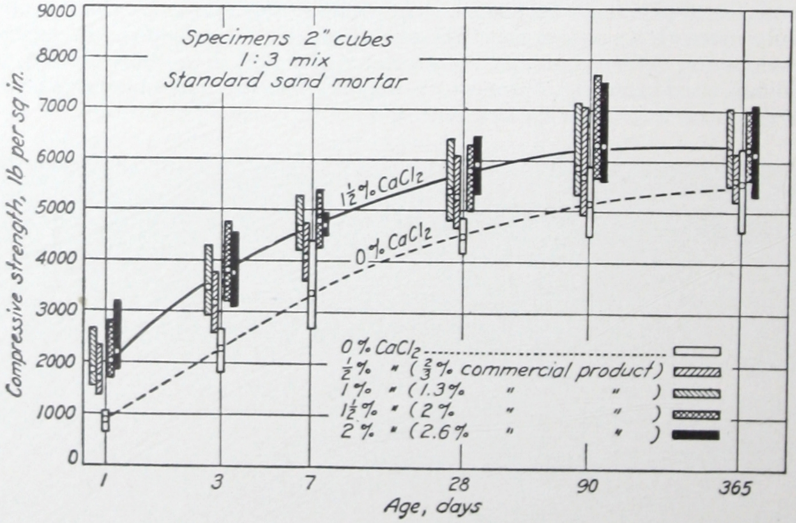


Figure 10.—Comprehensive Strength of Eight Standard Portland Cements, 1:3 Standard Sand Mortars.. (From National Bureau of Standards Report.)

at 1 day is practically doubled by the use of this amount of calcium chloride. The strengths of the mortars containing white cement were similarly affected by the addition of calcium chloride. The strength of the mortar made with high-early-strength cement was also increased by the addition of calcium chloride; the strengths in all cases being higher than those of the 8 standard cements.

1:2:4 STANDARD CEMENT CONCRETES

The compressive strengths of the concretes of the standard cements are summarized in Figure 11. At 1 day the average strength of the concrete with 2 percent of commercial calcium chloride was 128 percent higher than the average strength of the plain concrete, at 28 days the increase was 13 percent, at 90 days 9 percent, and at 1 year 8 percent. It is to be noted that calcium chloride, besides producing a great increase at early ages, also increased the strength of the concretes up to 1 year, at which age the tests were terminated. The strengths of the concrete made with white and high-early-strength cement were likewise increased by the addition of calcium chloride."

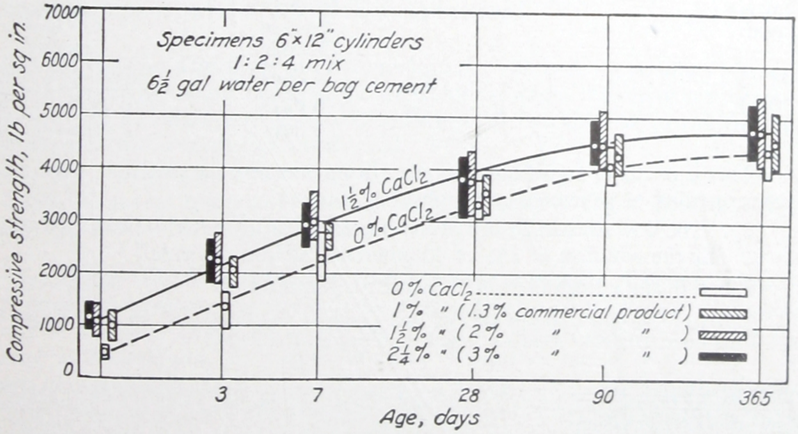


Figure 11.—Comprehensive Strength of Eight Standard Portland Cements, 1:2:4 Concrete. (From National Bureau of Standards Report.)

U. S. Bureau of Standards reports show that:

(a) "All concretes with calcium chloride have greater strength than the plain concrete."

(b) "The addition of calcium chloride increased the strength of all the cements at all ages up to one year, beyond which tests were not made. Not only were the early strengths greatly increased by the addition of calcium chloride, but the one year strengths were appreciably increased."

(c) "An increase in compressive strength of concrete due to the addition of 2% of flake calcium chloride" takes place as shown below—

Age at Test	Bureau of Standards	Portland Cement Assn.	District of Columbia
1 day	114% Gain		80% Gain
2 days		48% Gain	52% Gain
3 days	92% Gain		46% Gain
7 days	29% Gain	25% Gain	21% Gain
28 days	14% Gain	7% Gain	
90 days	7% Gain	7% Gain	
1 year	8% Gain	12% Gain	
3 years		9% Gain	

CURING TIME SAVED

(d) "Effect of curing temperature and addition of calcium chloride on length of time required for concrete to attain 2500 lbs. per square in. strength" is as follows—

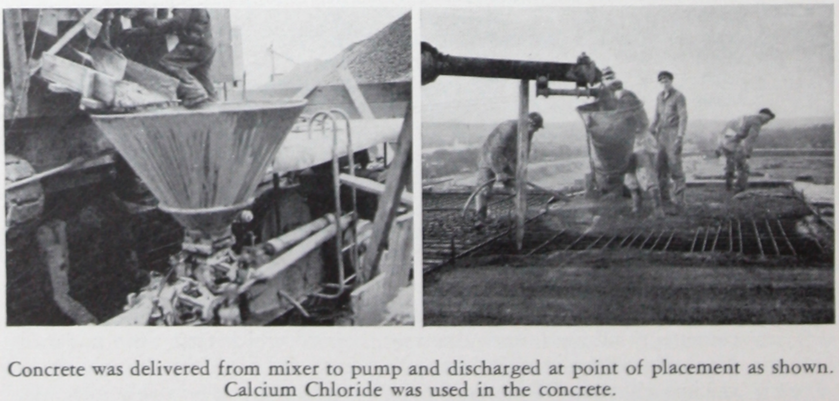
Temperature	Without Calcium Chloride	With Calcium Chloride
90° F.	4 days	2 days—(1½%)
70° F.	6 days	2½ days—(2%)
40° F.	14 days	7 days—(2%)

(This is of major significance in expediting concrete construction, permitting earlier opening of pavements or removal of forms.)

(e) "The flow or workability of the concrete was increased—from 29 to 41—by the addition of 2% of commercial calcium chloride."

(a, b, c, d, and e from Bureau of Standards Report.)

"Effect of Calcium Chloride on Portland Cements and Concretes" by Paul Rapp, Research Associate, Highway Research Board Proceedings, Dec., 1934.



Concrete was delivered from mixer to pump and discharged at point of placement as shown. Calcium Chloride was used in the concrete.

THE EFFECT OF CALCIUM CHLORIDE ON THE MAJOR COMPOUNDS OF PORTLAND CEMENT

"1. The heat contributed by the 4 major compounds of portland cement during the first 24 hours was determined on neat cement pastes and also with the pastes to which 1 percent of anhydrous calcium chloride was added. Factors are given from which the heat evolved in 24 hours by a portland cement may be computed from its compound composition, either with no calcium chloride or when 1 percent of anhydrous calcium chloride is present. The addition of calcium chloride increased the heat contributed by dicalcium silicate and tetracalcium alumino-ferrite, decreased the heat from tricalcium alumnite, and had little or no effect on the heat contributed by tricalcium silicate.

"2. The addition of calcium chloride increased the heart evolved by each of the cements tested up to 24 hours, even though that part of the total heat developed by the tricalcium aluminate was decreased. Although there was not much change in the total heat evolved in 24 hours, the addition of calcium chloride markedly increased the rapidity with which this heat was evolved."

The fact that an admixture of calcium chloride "had little or no effect" on the heat contributed by the hydration of the tricalcium silicates, the major constituent of cement is of significant interest, for the effect of calcium chloride in accelerating the hydration of this constituent is marked.

Since the major compounds have entirely different strength characteristics, their proportions in the cement affect the strength of the whole.

"Tricalcium silicate adds strength to the cement at all ages. Calcium chloride is effective in increasing the strength-contributing value of tricalcium silicate in cement at all ages tested. At 1 day the dicalcium silicate contributes little or nothing to the strength. At 7 days the effect is negative, but at 28 days there is a gain of approximately 4 lb./in. for each percent. The addition of calcium chloride increases the strength-contributing factor of the dicalcium silicate at the ages studied although it shows little effect at 1 day. At 7 days 2 percent of anhydrous calcium chloride increases the strength by about 7 lb./in. for each percent of dicalcium silicate and at 28 days this strength is increased by about 12 lb./in.

"Tricalcium aluminate adds to the strength at all ages up to 28 days. Calcium chloride increases the strength contributed by tricalcium aluminate at 1 day, but it decreases the strength at 7 and 28 days. The decrease is larger with increasing amounts of calcium chloride and is larger at 28 days.

"The strength contributed by tetracalcium alumino-ferrite is so small and the probable error is such that it is not known whether the contribution is positive or negative at any age. The addition of calcium chloride apparently makes these factors negative.

"Using the factors which give the strength contributed by the four major compounds in cement, and knowing the compound composition of the cement, a fairly accurate computation of the strength produced by the addition of calcium chloride can be obtained. Referring to Table 3 we see that the strength can be calculated for all cases, with probable errors ranging from 8 to 16 percent. With 2 percent of anhydrous calcium chloride the precision of the computed strength varies from 8 to 10 percent."

In Table 3 below the cement compounds are abbreviated as follows:

Compound	Chemical Formula	Abbreviation
Tricalcium silicate	$3CaO . SiO_2$	C_3S
Dicalcium silicate	$2CaO . SiO_2$	C_2S
Tricalcium aluminate	$3CaO . Al_2O_3$	C_3A
Tetracalcium alumino-ferrite	$4CaO . Al_2O_3Fe_2O_3$	C_4AF

Table 3.—Component compressive-strength factors, with and without calcium chloride, for sixty experimental cements

$CaCl_2$	Age	Strength factors (pounds per square inch for each percent of component).				Difference between calculated and observed strengths,* expressed as probable error.	
		C_3S	C_2S	C_3A	C_4AF		
percent	*Days*					lb./in.^{2}	*percent*
0	1	4.09±0.36	0.22±0.38	10.4±1.1	—2.7±1.2	±37	16
1		13.03±0.79	—1.03±0.83	15.1±2.3	—10.9±2.7	±81	14
2		13.91±0.61	—1.06±0.65	16.2±1.8	—8.7±2.1	±63	10
0	7	20.8±1.2	—4.1±1.2	47.6±3.4	—0.2±3.9	±119	10
1		31.8±1.6	0.2±1.7	41.3±4.9	—1.2±5.5	±168	10
2		33.7±1.5	3.4±1.5	33.1±4.4	—7.0±5.0	±151	9
0	28	30.2±1.6	3.9±1.6	88.9±4.6	—3.6±5.3	±160	8
1		41.2±1.9	13.8±2.1	58.1±5.8	—12.6±6.6	±201	8
2		46.1±1.9	16.0±2.0	38.5±5.7	—18.8±6.5	±197	8

* For each cement the strength was calculated from the factors. The probable errors given are computed from the difference (d) between the calculated and observed strengths for each cement by the equation: $\text{Probable error} = .6745 \sqrt{\frac{\Sigma d^2}{n\text{-}1}}$

From National Bureau of Standards Report

As has been established, early strength concrete obtained by increasing the unit cement or by using "High-Early" strength cements develops an enormous amount of heat. These research studies reported by the National Bureau of Standards, however, establish the important phenomenon that the rate of hydration of cement may be greatly accelerated, through integral curing with calcium chloride, without appreciably increasing the amount of heat developed.

WORKABILITY OF CONCRETE INCREASED WITH CALCIUM CHLORIDE

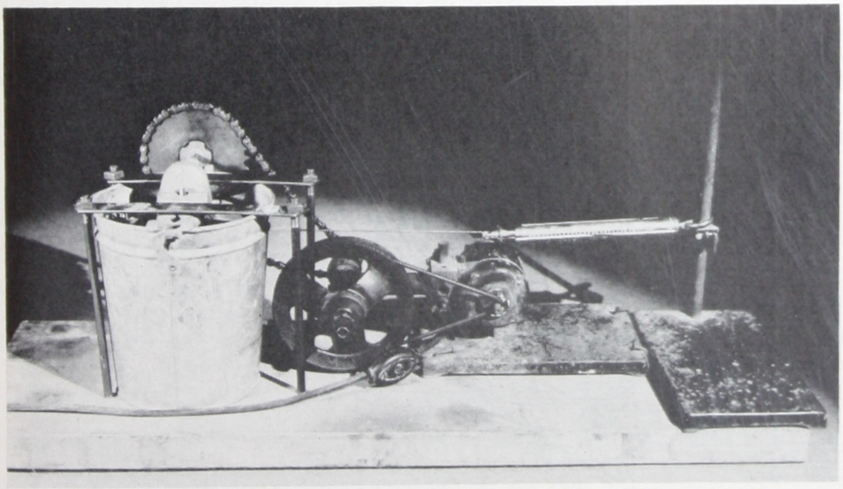
(From a paper by Herman Miller)

The following abstracts are taken from a paper by Herman Miller discussing the effects of calcium chloride admixture on the workability of concrete. The experiments were designed to establish the allowable working time of mass concrete in transit. Mr. Miller stated in part as follows:

The ease with which concrete can be placed depends on the workability of the mix, that is, the ease with which the material flows while at the same time it remains coherent and resists segregation. Workability is a factor easily appreciated in practice but in the past has been hard to measure in the laboratory. However, recently we have been able to measure with a fair degree of accuracy the workability of neat cement mixes, mortar mixes and concrete mixes, with and without admixtures of calcium chloride.

SPECIAL EQUIPMENT

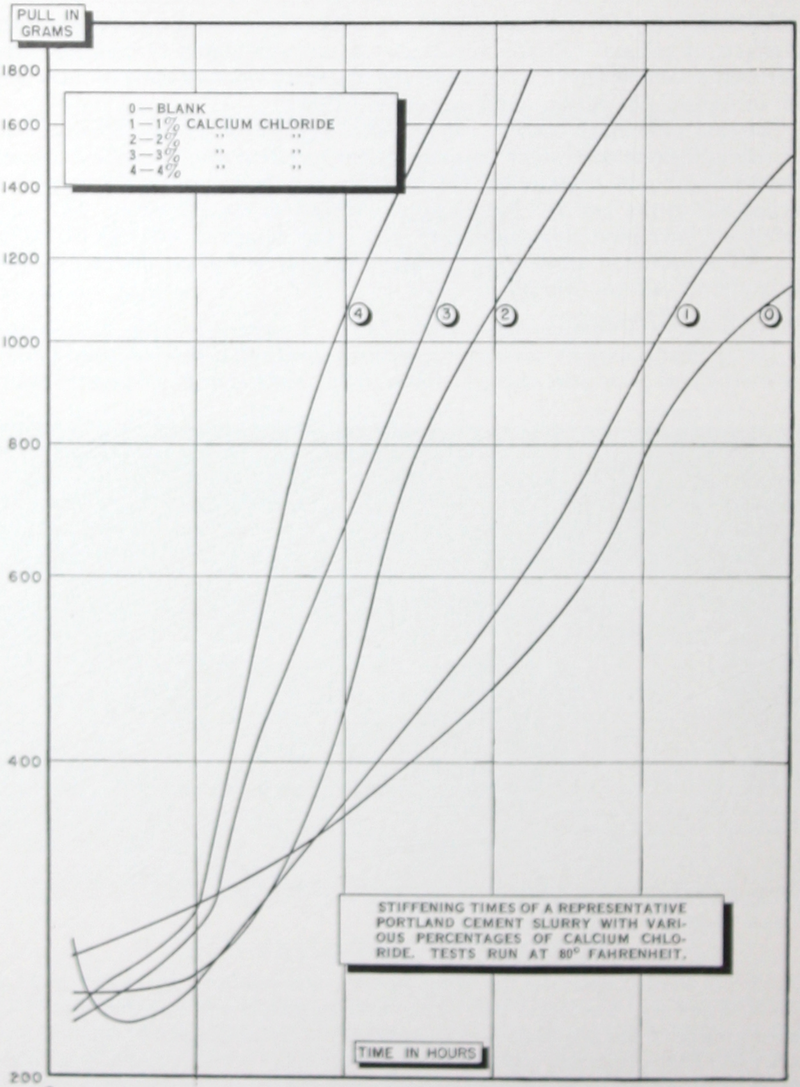
The apparatus used for performing these tests was a modified ice cream freezer. The mechanical parts were changed about so that the freezing-can pivoted freely.



WORKABILITY TEST APPARATUS

The center shaft containing the wing paddles was removed and re-set so as to remain stationary. The outer part of the mixing paddle was motor driven. One end of a piece of flexible chain was attached to the circumference of the can. The other end of the chain was attached to a spring balance which was anchored independently of the can. The machine was geared so that the turning paddles revolved at the rate of 24 r. p. m. The tests were conducted by mixing (1) 2500 grams of neat cement and (2) 2500 grams of a 1-2-3- concrete mix, with and without the admixture of calcium chloride, and the amounts of water necessary to give normal consistency.

Immediately after premixing the test compositions for two minutes they were placed in the apparatus (the freezing can) and the machine-mixing was begun.



STIFFENING TIMES OF A REPRESENTATIVE PORTLAND CEMENT SLURRY WITH VARIOUS PERCENTAGES OF CALCIUM CHLORIDE. TESTS RUN AT 80° FAHRENHEIT.

GRAPH A

The reading of the pull, in grams, exerted by the resistance of the contents of the inner can was taken at 10-minute intervals. The outer chamber was filled with water and kept at a constant temperature during the test.

The elapsed times from the initial mixing to the occurance of a 1120 grams pull in case of neat cement, and 1800 grams pull in case of the aggregate mix, were considered the working times of the mixtures.

Graph A shows the stiffening time of a representative Portland cement concrete, 1-2-3- mix, with and without calcium chloride. The calcium chloride, as indicated on the charts, was based on the weight of the cement.

The additions of calcium chloride (1-2-3 and 4 per cent) in both mixes show that the admixture has considerable effect on the workability of the material. In Graph A the pull in grams during the first hour of mixing is on an average of 30% less where the clacium chloride was incorporated. It is evident, therefore, that the early workability of the concrete was definitely improved by the admixture.

EFFECT ON TRANSIT TIME

The question often arises as to what is the effect of calcium chloride on the allowable working time of mass concrete in transit. From Graph A, it is noted that the 2, 3 and 4 per cent calcium chloride admixtures cross the untreated concrete at 1¼ hours. This indicates that mass concrete under continuous mixing at 80° F. would have a safe working time at 1¼ hours, as compared with 3¾ hours for the untreated mix.

It is also noted that during the first hour the improved workability is an important factor as shown in Table No. 1.

Assuming from Table I that neat concrete has a workability of 100% then by the addition of calcium chloride the workability is improved as much as 44% as shown in Table II. The admixture also produces greater density in concrete thereby furnishing resistance to disintegrating forces, eliminates honey-combed sections, and aids in preventing segregation.

TEMPERATURE FACTOR

The stiffening time of both cements and concrete is greatly effected by temperature but the improved workability is obtained by the use of calcium chloride whether the tests were run at 60° F., 80° F., or 120° F. One representative neat cement had a stiffening time of 9 hours at 60° F., 6 hours at 80° F., and 2 hours at 120° F. This same cement with 2% calcium chloride, based on the weight of the cement, had a stiffening time of 3 hours at 60° F., 2 hours at 80° F., and less than 1 hour at 120° F. The improved workability curve followed the same general trend.

EFFECT OF PROLONGED AGITATION

To ascertain whether or not the prolonged agitation would have any detrimental effect on the concrete, test specimens were cast from the original mix and from the resulting mixture after completion of the stiffening time tests, which varied from 2 to 5 hours. These specimens were cured for 3 days in wet burlap and then stored in a humidity chamber until tested at 7 and 28 days. The prolonged agitation did not appreciably effect the ultimate strength of the concrete. When the compressive strengths were plotted on a graph they showed the same relative increases in strength due to the addition of calcium chloride.

TABLE NO. 1

Calcium Chloride Admixture	Grams Pull Exerted		
	10 Minutes	30 Minutes	1 Hour
0.0%	380	320	325
1.0%	230	240	220
2.0%	280	240	250
3.0%	250	180	250
4.0%	250	200	250

TABLE NO. 2

Calcium Chloride Admixture	Per Cent Workability		
	10 Minutes	30 Minutes	1 Hour
0.0%	100	100	100
1.0%	116	125	132
2.0%	126	125	125
3.0%	134	144	125
4.0%	134	138	125

Concrete for foundations and floors of the Kalamazoo, Mich. State Hospital contained calcium chloride for added workability in winter transit mix delivery.

EFFECT OF CALCIUM CHLORIDE ON THE STRENGTH OF CONCRETE EXPOSED TO LOW TEMPERATURES

Excerpts from a paper presented to Highway Research Board in November, 1941, covering tests by the National Bureau of Standards.

The reported work done at low temperatures was a continuation of the study of the effect of calcium chloride on portland cements and concretes inaugurated in 1932 and on which a report was presented by Rapp in 1934. A fellowship was re-established at the National Bureau of Standards in June of 1939 for the continuation of the work.

Concrete cylinders were subjected immediately after preparation at 70° F. to temperatures varying from 20 to 40° F. and maintained at these temperatures until one day before testing in compression. Comparative mixes were made with 2, 3, and 4 per cent of calcium chloride by weight of cement. The following conclusions have been drawn from the investigation:

(1) As in the case of higher temperatures, concrete integrally cured with calcium chloride has greater strength at all ages at temperatures as low as 20° F. studied in this series of tests. At freezing temperatures (32° F. and below) and at early ages three and four per cent of calcium chloride by weight of the cement produced greater strength concrete than 2 per cent, the amount normally used at higher temperatures.

(2) *At 20° F.* integral curing with calcium chloride provided cold weather protection; however, plain concrete at this temperature developed no strength throughout the 28-day observation period.

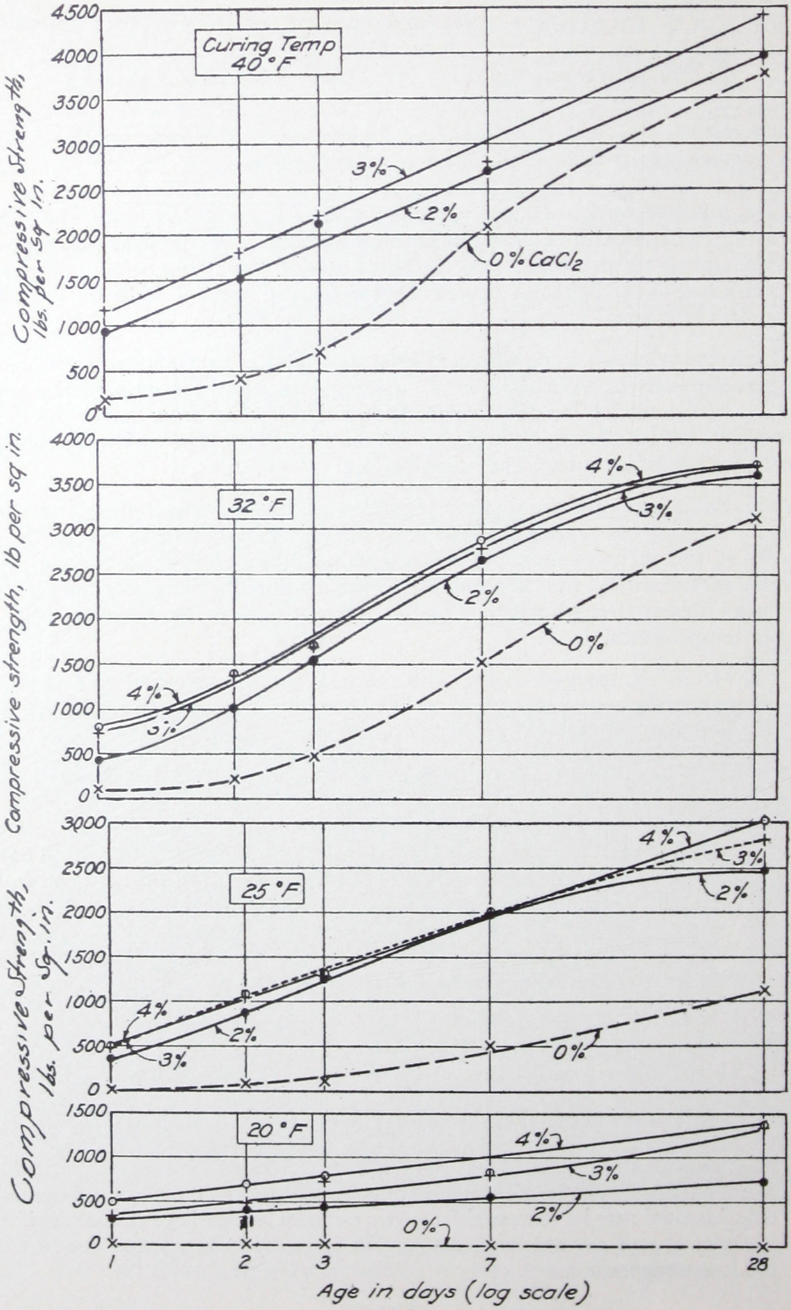
At 25° F. concrete cured with 4 per cent of calcium chloride developed strength in a normal manner, 2000 lb. strengths being attained in 7 days; plain concrete developed no strength at 1 day, thereafter the rate of development was gradual, 1130 p.s.i. strength being attained in 28 days. *At 32° F.* concrete cured with 4 per cent of calcium chloride gained early strength rapidly (1710 p.s.i. at 3 days), and as in the case of all series attained greater strength than the plain concrete at 28 days; plain concrete gained early strength slowly (470 p.s.i. at 3 days), although subsequent strength development was normal (3150 p.s.i. at 28 days).

At 40° F. concrete cured with 2 per cent of calcium chloride developed a strength of 2130 p.s.i. in 3 days and of 5980 p.s.i. in 28 days, strengths of plain concrete at the same ages were 700 and 3780 p.s.i. respectively.

(3) The strength accelerating value of calcium chloride integral curing becomes more pronounced as the concreting temperature lowers.

Recommendations: At freezing temperatures and lower the amount of calcium chloride used may be increased from two per cent, which is generally specified, to three or four per cent according to the intensity and expected duration of the low temperature.

FIGURE I


Curing Temp 40°F
3%
2%
0% CaCl2
Compressive Strength, lbs. per sq in.
4500
4000
3500
3000
2500
2000
1500
1000
500
0
32°F
4%
3%
2%
0%
Compressive strength, lb per sq in.
4000
3500
3000
2500
2000
1500
1000
500
0
25°F
4%
3%
2%
0%
Compressive Strength, lbs. per sq. in.
3000
2500
2000
1500
1000
500
0
20°F
4%
3%
2%
0%
1500
1000
500
0
1
2
3
7
28
Age in days (log scale)

The tests relating to the effect of low temperatures and calcium chloride on the rate of strength development of concrete are reprinted in part herewith.

TEST RESULTS

Table I gives the average compressive strength of the concretes at the various ages and for the several storage temperatures. The data are presented graphically in Figure 1. Each compressive strength given is the average of three cylinders.

TABLE I

COMPRESSIVE STRENGTH OF CONCRETE

Specimens: 6 x 12-in. cylinders
Mix: 1:2:4 by weight
Water content 6½ gals. per sack

Aggregate:
Fine: Potomac River Sand
Coarse: Potomac River Gravel
Cement: Cement "C," Standard Portland

Temperature ° F.	Calcium Chloride Pct. Commercial		Compressive Strength in lbs./sq.inch			
		1 day	2 Days	3 Days	7 Days	28 Days
20	0	0	0	0	0	0
	2	290	400	430	550	730
	3	320	480	710	820	1320
	4	500	700	780	830	1370
25	0	0	80	100	510	1130
	2	350	870	1250	1970	2470
	3	470	1030	1270	1990	2810
	4	550	1070	1310	2000	3030
32	0	100	210	470	1530	3150
	2	430	1030	1550	2660	3610
	3	750	1370	1690	2790	3730
	4	790	1380	1710	2890	3730
40	0	170	410	700	2100	3780
	2	950	1520	2130	2710	3980
	3	1180	1810	2220	2790	4410

Graphs covering tests are shown on page 50.

EFFECT OF CALCIUM CHLORIDE IN OIL-WELL CEMENTS

Abstracts from a paper by F. N. ALQUIST and H. H. MILLER
From Oil and Gas Journal, July 17, 1941

Many special cements have been developed for use in oil and gas-well cementing operations with a view to obtaining high early strength, faster set, greater durability, and easily pumpable slurries. Although some of these qualities can be obtained by the appropriate addition of calcium chloride to ordinary cements, this knowledge does not appear to have been generally utilized by the oil industry. It is the purpose of this paper to bring to the attention of the industry information upon how calcium chloride may be used advantageously with portland cements to improve their fitness for oil-field use.

The use of calcium chloride in the proper proportions with standard portland cement imparts to the slurry properties that are very desirable for surface jobs and for all intermediate and oil strings where bottom-hole temperatures are low. From both the material and the operating standpoints, savings definitely can be effected by the addition of calcium chloride to cement slurry. Considering the availability and low cost of calcium chloride, there is no reason why this technique of cementing oil wells should not be more generally utilized.

Integral admixing of calcium chloride with portland cement concrete is an established practice as the most efficient and economical method of accelerating the setting of cement. Its use is widely recognized in modern concrete practice and many tons of calcium chloride were used in the construction of the Grand Coulee and Bartlett dams, as well as many other Bureau of Reclamation projects. Calcium chloride is also used in structural concrete, highways and concrete products. The additional cost of calcium chloride is nominal as compared with the advantages gained by its use since it (1) imparts high early strength which permits early removal of forms, quicker finishing, and the use of the structure or product , because strength is gained in half the time; (2) insures better workability by maintaining uniform moisture and increasing the density of the mass concrete and (3) reduces materially the shrinkage of cement mixture.

All of the above advantages accrue when calcium chloride is used with neat portland cement for oil-well cementing.

ESSENTIAL CHARACTERISTICS

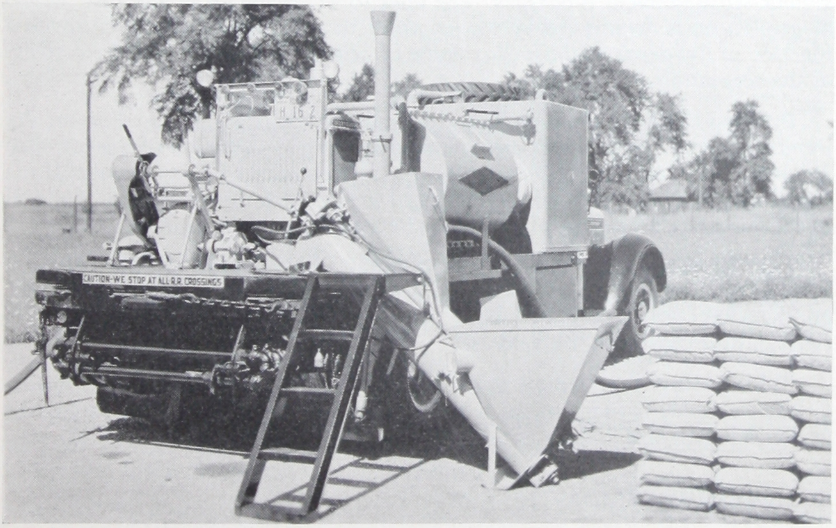
Field data on oil-well cements and laboratory tests, using the standard American Petroleum Institute cement-testing methods, definitely indicate that cements suitable for oil-well use must be able to function under conditions different from those encountered in construction work. To provide satisfactory performance for casing cementing, plugbacks, squeeze jobs, casing seats, etc., cement should possess the following essential characteristics: (*a*) Make a uniform slurry, (*b*) remain pumpable for a sufficient time to allow placing, (*c*) maintain fluidity regardless of wall conditions in the well, (*d*) set rapidly when in place, (*e*) produce high early strength (*f*) form an impermeable mass, (*g*) be permanent under varying conditions.

The oil-well operator has at least six types of cement available: (1) Regular portland cement, (2) retarded portland cement, (3) accelerated portland cement, (4) high early-strength cement, (5) oil-well cements, and (6) special oil-well cements.

Time required for a cement to harden in a well is a loss that delays subsequent activities. Improvements in materials and equipment have cut this lost time from 30 days or more to 8 hours and in some instances even less. A quick set and high early strength of cement have contributed to this speed of getting wells into production.

The most important factors which affect the success of a cement job are the characteristics of the formation within the well. The cementing engineer must recognize these varying characteristics and choose a suitable type of cement and the best equipment available to insure satisfactory results.

Cementing is usually done by an independent company specializing in this operation. Equipment used to mix and place the cement which is usually mounted on a large truck includes two open-top water-storage or measuring tanks, a mechanical or jet-type cement mixer, a slurry pump driven by the truck motor or by steam as the case may be, and an auxiliary water pump. The mixing of the cement and water is accomplished by an independently driven mixer, or, if a jet mixer is used, by an auxiliary motor-driven mixing pump. The successful completion of an oil-well cementing job is contingent upon the correct proportioning of cement and water to obtain the desired properties. In order to get this correct proportion it is essential that the cementing equipment be provided with a mechanically controlled device which will accurately proportion the cement and water in the desired ratio. The cement may be added to the mixer by bags or by an automatic conveyor system.



Cementing Truck with Special Equipment

Cementing is started by lowering the casing to the bottom of the well and raising to clear bottom. Mud or well-fluid circulation is then established in most cases to assure the cementing engineer that the well is in proper condition for successful cementing.

Dry cement can be fed to the mixer at an average rate up to 30 bags per minute and if this is not rapid enough more than one mixer can be used. When all the cement slurry has been added, a plug is inserted into the casing to separate the cement from the placing fluid. The depth to which the top plug is placed is determined by accurately measuring the volume displacement of the placing fluid, by following it with a measuring line or by pumping the plug to a shutoff against a casing shoe or some similar restriction in the casing. A few feet of cement is usually left in the casing to assure that clean uncontaminated slurry is spotted around the casing seat. The casing is then lowered to the bottom and the top valve is closed to prevent any disturbance during setting.

Since drilling cannot be resumed until the cement has set, the desirability of a quick-setting cement is obvious. The limit to which the set of a cement should be accelerated is determined by the length of time required to place it, and is a function of the depth of the well, volume of cement to be used, and the capacity of the cementing equipment.

Portland cement containing 2 or 3 per cent calcium chloride based on the dry weight of the cement is applicable in cases requiring an initial set of not less than 2½ hours and a final set of 4½ to 5 hours as determined by Vicat needle. If the temperatures of the hole and mixing water are normal, the drilling-in of a well so cemented can be resumed in 8 hours after the first cement is mixed.

Calcium chloride has been used successfully with portland cement in the oil fields of Michigan, Illinois, Kansas, California, Oklahoma, Texas, and other states, but there has been no published data on the effect of calcium chloride on the properties of neat cement for oil-field use.

Table 1 lists some typical examples of calcium chloride field applications. Calcium chloride is added to the water used to mix the cement, or the dry flakes or powder are added directly to the cement mixer.

COMPRESSIVE STRENGTH

The usefulness of an oil-well cement depends on its ability to harden and develop a high early strength permitting drilling to be resumed with as little delay as possible. The curing conditions are designed to comply as nearly as possible with well conditions. In the standard American Petroleum Institute method, 2-in. cubes are cured in water at 150° F. and at 1, 3, and 7-day intervals. In order to show the adaptability of calcium chloride to relatively low-temperature use, cubes were cured at 60°, 110°, and 150° F. These cubes were made of a slurry of standard fluidity as determined by the ring test and allowed to harden in the water bath. They remained in the water until they were taken out to be broken. The optimum amount of calcium chloride to give the greatest increase in strength was 2 to 3 per cent by weight of the cement.

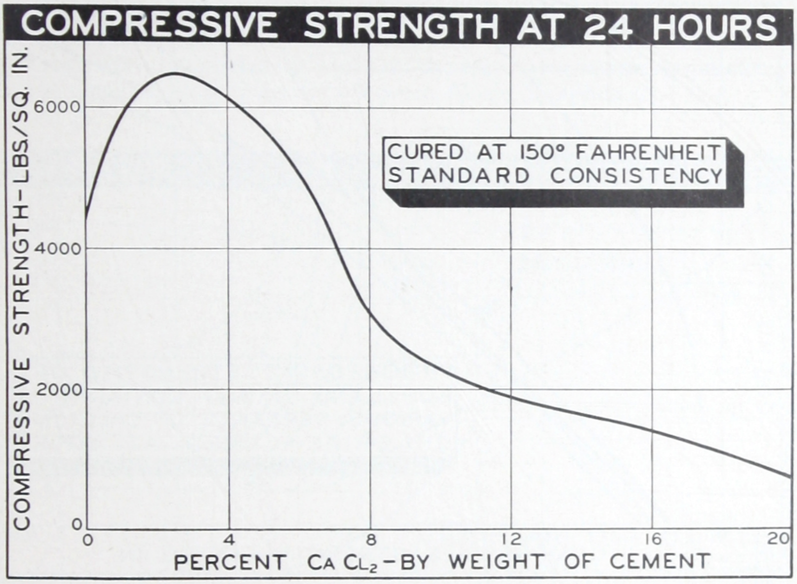


Fig. 3

Fig. 3 shows the general effect of varying the percentages of calcium chloride up to 20 per cent of the weight of the cement and cured at 150° F. The important conclusion to be drawn from this curve from the viewpoint of field application is that low percentage, preferably between 2 and 3 per cent calcium chloride, give optimum increases of compressive strength.

Fig. 4 shows the effect of varying the length of curing time at 60° F. with up to 6 per cent calcium chloride. The data definitely indicates advantages of calcium chloride at low temperatures with curing times up to 24 hours.

Most work by previous investigators on the effect of calcium chloride on either concrete or neat cement, as well as our present data, have been studied by compressive and tensile-strength methods. The results of such tests definitely show that the addition of 2 to 3 per cent calcium chloride to portland cements increases the high early strength. Oil-well operators can take advantage of this property as well as users of concrete. The main difficulty in a more widespread oil-field use has been that the effect of calcium chloride on the compressive strength of a large number of oil-well cements had not been definitely measured under a wide enough set of conditions so far as temperature and proportions of calcium chloride are concerned. However, both our laboratory tests and field experience show that if 2 to 3 per cent calcium chloride is used with regular portland cement, no trouble will be encountered when handled by proper methods.

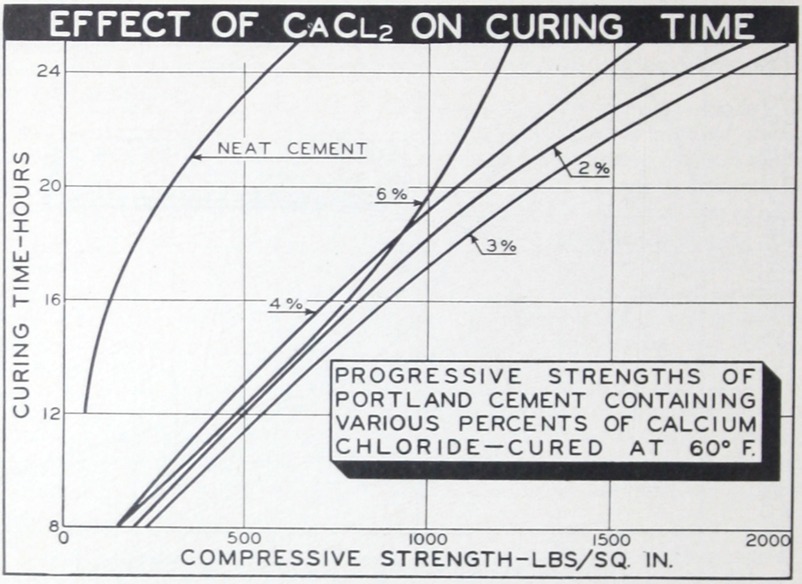


Fig. 4

THICKENING TIME

In choosing a cement for oil-well use it is necessary to know the length of time that it remains in a pumpable state under well conditions. The machine used for this measurement is the one developed by the Standard Oil Co. of California. Equipment consists of a slurry container which is surrounded by a water bath complete with a rheostat paddle stirrer and thermostat. The slurry is placed in the container at 80° F. and the bath temperature is raised 1° a minute until 140° F. is obtained. The temperature is then kept constant for the duration of the run. The stage of pumpability is measured by taking the torque readings on a spring scale attached to the slurry container. When the pull reaches 40 oz., the limit of the pumping stage is reached.

To determine the suitability of calcium chloride cement as relatively low temperatures, tests were also made using the same apparatus but allowing the temperature to remain at 80° F. The thickening-time test by the American Petroleum Institute standard procedure, or at a fixed low temperature, 60° or 80° F., shows that calcium chloride accelerates the thickening time of cements considerably and that the use of calcium chloride is not feasible on deep wells where it takes longer than 45 to 60 minutes to mix, pump and place the cement. Calcium chloride may be used satisfactorily on the low-temperature wells where it has been recommended. Fig. 5 shows that the thickening times are decreased with increasing percentages of calcium chloride from 2 hours to between 40 and 50 minutes.

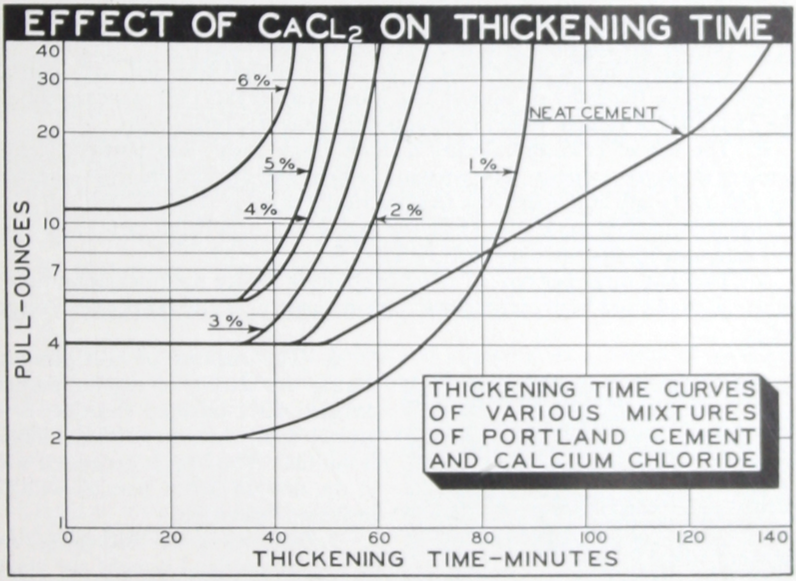


Fig. 5

TIME SAVING

Time is especially important in oil-well operations when crews are unable to proceed with drilling operations. Our field experiments confirm laboratory findings and show that sufficient strength is obtained using regular portland cement with 2 to 3 per cent calcium chloride so that drilling operations can be started up with only a minimum delay.

COSTS

Present practice calls for the use either of relatively expensive special oil-well cements or "high early" cement, whereas the technique employing the addition of calcium chloride is simple and allows the relatively cheap ordinary portland cement to be used instead. Engineers in charge of well operations can readily make their own cost comparison for any job under consideration based on market prices and the data available in this article.

CONCLUSIONS

1. The use of regular portland cement with 2 or 3 per cent calcium chloride added offers a saving of time and money to oil operators in cementing surface and low-temperature strings. The calcium chloride can be added in the form of a flake, a powder, or a solution, with the same results in every case.

2. The final setting time of regular portland cement is reduced approximately 50 per cent by the addition of 2 to 3 per cent calcium chloride.

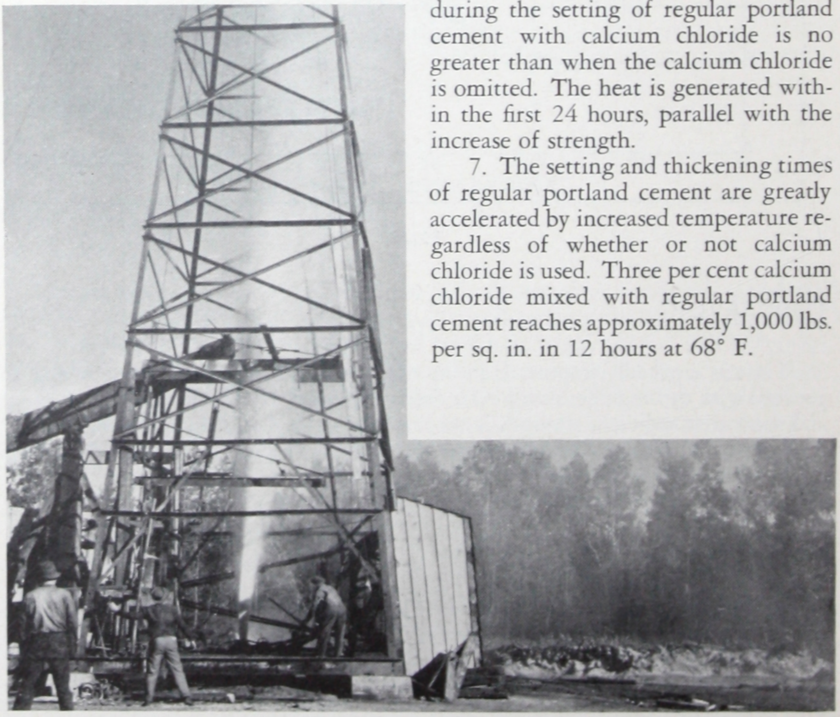
3. Quantities up to 4 per cent of calcium chloride admixed with portland cement require the same or slightly less water-cement ratio for standard fluidity. The 25 brands of cement tested gave approximately uniform results.

4. The use of calcium chloride in both "high early" and portland cement increases the early strength. The portland cement and calcium chloride admixture acquired a strength at 8 hours that was practically equal to that of "high early" and calcium chloride and more than twice the strength of neat "high early" at 8 hours. This held true whether tested at 60° or 150° F.

5. Two and three per cent of calcium chloride reduce the thickening time of regular portland and high early cement approximately 50 and 66 per cent, respectively.

6. The quantity of heat generated during the setting of regular portland cement with calcium chloride is no greater than when the calcium chloride is omitted. The heat is generated within the first 24 hours, parallel with the increase of strength.

7. The setting and thickening times of regular portland cement are greatly accelerated by increased temperature regardless of whether or not calcium chloride is used. Three per cent calcium chloride mixed with regular portland cement reaches approximately 1,000 lbs. per sq. in. in 12 hours at 68° F.



A Michigan well, drilled in after cementing.

SPECIFICATION SECTION

Calcium Chloride is applied to the surface of or incorporated into concrete mixes in several ways and standard specifications are available for each method.

SURFACE CURING

Curing by applying Calcium Chloride to the surface of pavements, walks and other flat surfaces is used in cases where acceleration of set, high early strength and early use are not necessary. It is also used in cases where specifiactions were completed before integral use of Calcium Chloride had attained its present proved standing and specifications have not yet been revised to include the more advantageous integral uses in the mix itself.

Surface curing prevents the rapid evaporation of the mixing water, thus preventing serious volume change with its attendant weakening and checking, gives a superior wear-resisting surface to the concrete slab, and yields ultimate strengths equal if not superior to the same concrete mixes cured with dirt and water.

ADMIXTURE METHOD—SOLUTION FORM

This method was established, tested and approved as a means of including Calcium Chloride in solution form before adequate research had shown that it could be included more rapidly in dry form and that when so included it goes into solution almost as soon as the mixing water is added to the batch. Specifications for introduction by solution method are given for the benefit of those who are governed by such specifications.

Diagrams for mechanical methods of making solution and means of measuring and of introducing into the mixer will be supplied on request.

ADMIXTURE METHOD—DRY FORM

This method appears to be the simplest and most economical means of incorporating Calcium Chloride in the mix since it requires no making of solutions, no containers for solution nor any pipes, pumps, measuring devices or other mechanisms for introducing the material into the mix. The only equipment needed is a measure of proper size for introducing the exact amount of dry flake Calcium Chloride required for each batch, the material being introduced into the aggregate before mixing water is added. Simple dippers, cans or other measures are all the mechanism required when Calcium Chloride is used in the form of dry flake.

USE OF CALCIUM CHLORIDE WITH HEATED AGGREGATES

The use of heated water and aggregates is generally recognized as good practice during cold weather. However, this precautionary measure will not alone safeguard the concrete nor assure the development of suitable strength. The addition of calcium chloride with heated aggregates and water will serve to compensate, largely if not wholly, for the normal drop in the temperature of concrete in the period following the pouring. In using calcium chloride with heated water and aggregates care should be taken to see that the temperature of the water and aggregates is not raised too high. A combination of high temperature and calcium chloride might accelerate the set to a point where finishing would be made difficult.

RECOMMENDATIONS ON THE INTEGRAL USE OF CALCIUM CHLORIDE

GENERAL RECOMMENDATIONS

77-80% Flake Calcium Chloride may be added to the mix in either the dry form (as it comes from the package) or in the form of a solution. The solution is made up of flake calcium and water in proportions that will result in a liquid each quart of which will be equivalent to one lb. of 77-80% flake calcium chloride. In the specifications in this section, one quart of standard solution can be substituted wherever one pound of flake material is shown.

Calcium chloride is always added to the mix in terms of "pounds per bag of portland cement." The quantities recommended vary from one pound per bag of cement for use when the temperature is above 90° F. to as much as four pounds per bag of cement during the lower range of temperatures. Maximum efficiency is obtained in the use of up to two pounds, the proportional reaction of quantities in excess of this amount being less marked except for cold weather protection.

When dry flake calcium chloride is used it should be added to and with the aggregate and not the cement. When solution is used it should be introduced with the mixing water (which should in all cases be reduced by at least the amount of calcium chloride solution used).

HOW TO PREPARE A STANDARD SOLUTION

Fill a 50 gallon barrel about 2/3 full of water, add 200 lbs. (2 bags or ½ drum) of Flake Calcium Chloride and stir until the flakes have completely dissolved. Then add enough water to fill the barrel and stir again to assure a uniform concentration. This will produce 50 gallons of a standard solution having four pounds of calcium chloride in a gallon, or one pound in a quart. Smaller quantities can of course be made up by using the same method and proportions.

QUANTITIES RECOMMENDED PER BAG OF PORTLAND CEMENT

For temperatures above 90° F.—1 lb.
For temperatures 80 to 90° F.—1½ lbs.
For temperatures 32 to 80° F.—2 lbs.
For temperatures below 32° F.—3 to 5 lbs., depending upon prevailing temperature conditions and amount of protection furnished.

EQUIPMENT FOR MEASURING AND ADDING CALCIUM CHLORIDE

Dry flake calcium chloride can be measured and added by means of any container which will hold the quantity required for each batch. Simply weigh out the amount of calcium chloride required for a batch and either mark the correct level on the side of the container or preferably shear off the top of the container at the mark. For adding liquid by hand a regular liquid measure can be used.

For measuring and adding liquid automatically, several different styles and types of special equipment have been designed. Some of this equipment can be easily built by any ordinary mechanic, some of it can be assembled from standard parts which can be purchased. In addition complete devices can be purchased from a number of manufacturers of paving supplies and equipment. We will be glad to furnish details regarding these devices on request.

AMERICAN SOCIETY FOR TESTING MATERIALS—SPECIFICATIONS FOR CURING PORTLAND CEMENT CONCRETE WITH CALCIUM CHLORIDE ADMIXTURE

A.S.T.M. STANDARD SPECIFICATIONS C-82-38

(From pages 104-5 — 1938 supplement to Book of A.S.T.M. Standards)

1. These specifications cover the method of curing portland cement concrete by accelerating the setting and hardening of the concrete by means of calcium chloride incorporated with the mixture.

2. The calcium chloride shall conform to the standard specifications for Calcium Chloride (A. S. T. M. Designation: D-98) of the American Society for Testing Materials.

3. Use of Calcium Chloride. Calcium chloride may be added to the mix in either the dry or solution form, as follows:

(a) When used in the dry form from 1 to 2 lbs. of calcium chloride per bag of cement, according to the temperature* prevailing at the time of concreting, shall be placed in the skip with the aggregates but not in contact with the cement, just prior to discharging the contents of the skip into the mixer drum.

(b) When used in the solution form the following procedure shall be followed in the preparation and addition of the solution to the concrete mix: Dissolve one bag of calcium chloride (100 lb.) in a quantity of water sufficient to make 25 gal. of solution (100 qt.). The solution shall be thoroughly stirred until it is of uniform concentration. From 1 to 2 qts. of this solution per bag of cement, according to the temperature* prevailing at the time of concreting shall be introduced into the drum of the mixer with the mixing water. The quantity of mixing water shall be reduced by the amount of calcium chloride solution used. A positive method shall be used for introducing the calcium chloride solution.

4. The concrete shall be finished and edged promptly after placing, as concrete containing calcium chloride hardens more rapidly than plain concrete.

5. After the final finishing operation the concrete shall be covered for not less than 24 hours by a double thickness of burlap, kept saturated with water. The burlap shall weigh when dry at least 7 oz. per sq. yd. It shall be handled in such manner that contact with earth or other deleterious substances will be prevented. Burlap which becomes contaminated with earth or other deleterious substances shall be washed clean before use.

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*The following amounts are recommended: At temperatures below 80° F. (27° C.), 2 lbs.; 80 to 90° F. (27 to 32° C.), 1.5 lbs.; above 90° F. (32° C.), 1 lb. (1 qt. of solution contains 1 lb. of calcium chloride.)

STANDARD SPECIFICATIONS FOR SURFACE CURING WITH CALCIUM CHLORIDE

A.S.T.M. DESIGNATION: C83-38 ADOPTED 1934, REVISED 1936, 1938, BY THE AMERICAN SOCIETY FOR TESTING MATERIALS

1. These specifications cover the method of curing exposed Portland cement concrete slabs by maintaining the surface moisture of the concrete by means of surface application of calcium chloride.

2. The calcium chloride shall conform to the standard speifications for calcium chloride (A. S. T. M. Designation: D 98) of the American Society for Testing Materials.

3. After the final finishing operation, the concrete shall be covered by a double thickness of burlap, kept saturated with water. The burlap shall remain until the concrete will bear the weight of the workman without damage, but in no case less than 12 hours. The burlap shall weigh when dry at least 7 ounces per square yard. It shall be handled in such a manner that contact with earth or other deleterious substances will be prevented. Burlap which becomes contaminated with earth or other deleterious substances shall be washed clean before use.

4. (a) After removal of the burlap, the pavement shall be sprinkled with water and 1.5 lbs. of calcium chloride shall be immediately applied to each square yard of the pavement surface. The material shall be spread by means of a squeegee or suitable mechanical device, and shall be screeded or belted upon dissolution to insure uniform coverage of the concrete slab.

(b) All lumps of calcium chloride shall be broken up and distributed uniformly or removed. Calcium chloride shall not be applied during a rain, and if a rain occurs within 2 hours after placing, the calcium chloride shall be replaced.

STANDARD SPECIFICATIONS FOR CALCIUM CHLORIDE

A. S. T. M. DESIGNATION: D 98-34, ADOPTED IN AMENDED FORM, 1934, BY THE AMERICAN SOCIETY FOR TESTING MATERIALS

SCOPE

1. These specifications cover calcium chloride to be used for road purposes, acceleration of concrete and curing of concrete.

PHYSICAL PROPERTIES

2. The calcium chloride shall be in the form of flakes, and when tested by means of laboratory screens and sieves shall conform to the following requirements:

Passing ⅜-inch screen	100%
Retained on ¼-inch screen	not more than 20%
Passing No. 20 sieve	not more than 10%

CHEMICAL COMPOSITION

3. The calcium chloride shall conform to the following requirements as to chemical composition:

$CaCl_2$ (anhydrous)	not less than 77.0%
$MgCl_2$	not more than 0.5%
Total alkali chlorides	not more than 2.0%
Other impurities	not more than 1.0%

PACKING AND MARKING

4. The calcium chloride shall be delivered in moisture-proof bags or sacks containing approximately 100 pounds each, or in air-tight steel drums weighing not more than 450 pounds each.. The name of the manufacturer, the lot number, the approximate net weight, and the percentage of calcium chloride guaranteed by the manufacturer shall be plainly marked on each container.

SHIPMENT, AVAILABILITY, ETC.

Calcium chloride is shipped in 100 pound improved moisture-proof reinforced paper bags or in 400 pound non-returnable light iron drums. The material, either in bags or drums, requires no more protection than that given cement.

Stock points are maintained in practically all important points in the United States, thus assuring prompt delivery. Carload shipments direct from the manufacturers can be made immediately upon receipt of order.

Ask for These
ASSOCIATION BULLETINS

These bulletins constitute a library of Calcium Chloride usage, and are available without charge to all interested persons. Simply address your request to Calcium Chloride Association, 4145 Penobscot Building, Detroit, Michigan.

Concrete Curing

Reprint No. 161—"Dry Flake Calcium Chloride Now Added Directly to Concrete Aggregates." Reprinted from February, 1941, issue of CONCRETE.

Brief No. 155—"For Full Speed Ahead in Concreting." Summarizes advantages gained with calcium chloride admixture.

Reprint No. 154—"Experiences Building and Curing Cement Concrete Roads," by Harry Tuthill, Superintendent of Highways, Suffolk County, New York. Reprinted from September, 1940, issue of PUBLIC WORKS.

"Early Strength Concrete—Effect of Temperature," American Road Builders' Association Bulletin No. 42, by H. F. Clemmer, Engineer of Materials, District of Columbia, Washington, D. C.

Ice Control

Bulletin No. 27—"Skidproofing Icy Roads and Streets"—A new 36-page treatise on ice control methods. It includes discussions on preparation and protection of stock piles—tells how to build storage bins for gravity loading and how to treat abrasives to secure greatest skidproofing values. Quotes experiences of highway officials in many states and municipalities.

Reprint No. 158—"Modernizing an Ice Control System," by E. L. Worthington, State Maintenance Engineer, West Virginia State Road Commission. Reprinted from January, 1941, issue of ROADS AND STREETS.

Reprint No. 157—"Preparation—Key to Speed on Ice Control." Describes operations of New Hampshire State Highway Dept. Reprinted from December, 1940, issue of BETTER ROADS.

Reprint No. 130—"Skidproofing Ice," by C. H. Jaquish, County Highway Commissioner, Dane County Wisconsin. Reprinted from PUBLIC SAFETY.

Stabilization
Surface Consolidation
and Dustless Maintenance

Bulletin No. 26—"Soil-Aggregate Stabilization with Calcium Chloride for Military Roads and Airport Runways."

"Use of Calcium Chloride in Road Stabilization"—a 40-page symposium on latest developments, released by the Highway Research Board, November, 1939.

Reprint No. 162—"What Price Low Cost Roads?" by Edward H. Nunn, Construction Engineer, Maryland State Roads Commission. Reprinted from May, 1941, issue of THE EARTH MOVER AND ROAD BUILDER.

Reprint No. 156—"Modernizing Old Roads in Ohio," by Frank Higley, Asst. Division Engineer. Reprinted from December, 1940, issue of EARTH MOVER AND ROAD BUILDER.

Reprint No. 141—"Consolidating Gravel County Road Surfaces," covering technique and results by four Michigan county engineers. Reprinted from BETTER ROADS.

Reprint No. 140—"The Maintenance of Gravel Roads," by W. H. Root, Maintenance Engineer, Iowa State Highway Commission. Reprinted from THE EARTH MOVER AND ROAD BUILDER.

Reprint No. 139—"How to Dustproof Roads and Streets of Gravel, Stone, Shell, Pebble-soil and Local Soil Mixtures."

Reprint No. 133—"Surface Treatment for Tennis Courts, Playgrounds, Private Drives, Etc."

Ask to be placed on mailing list for bi-monthly issues of The Calcium Chloride Association News.